This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Complim. the author

NOV 13 1950

THE AREAL AND ECONOMIC GEOLOGY OF NORTHEASTERN

(1) VERMONT.

(2) C. H. RICHARDSON, Ph. D., Syracuse University.

From the Fifth Report Vermont State Geologist.

Montpelier, Vt.,
Argus and Patriot Press.
1906.

G72

TN
172
R521

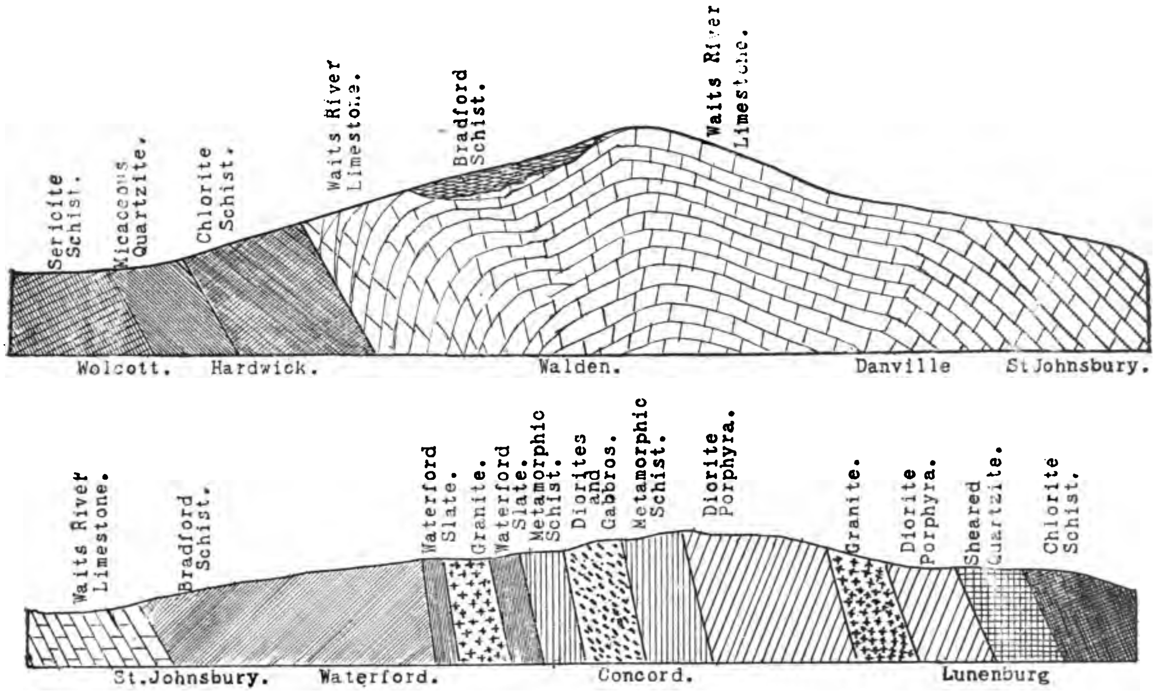
THE AREAL AND ECONOMIC GEOLOGY OF NORTHEASTERN VERMONT.

C. H. RICHARDSON, Ph. D., Syracuse University.

From the Fifth Report Vermont State Geologist.

MONTPELIER, VT.:
ARGUS AND PATRIOT PRESS
1906.

PLATE XVII.



Section from east to west across a part of North Eastern Vermont.
Vertical Scale 1:15,840.
Horizontal Scale 1:250,000.

The Areal and Economic Geology of Northeastern Vermont.

C. H. Richabdson, Syracuse University.

INTRODUCTION.

The present report upon the Areal and Economic Geology of Northeastern Vermont must be considered as a report of progress. When invited to study the North Country in 1904 it seemed possible to present in this Fifth Report of the State Geologist a detailed resume of all work done and required in the section assigned.

Time forbids accurate mapping and the plotting of the structural relations. These can be accomplished only in a generalized way without continued research in the field. The report therefore might be fittingly styled A Reconnaissance in Northeastern Vermont. The area chosen comprises Caledonia, Essex and Orleans counties with fifty-two townships, forty-one of which have been traversed. It includes also a small portion of Washington County.

Many photographs have been taken, a part of which appear as half tones in this article while the remainder are in the possession of the State Geologist. Two hundred and twenty-two carefully selected typical rock specimens of uniform size have been placed in the State Museum at Montpelier where both names and localities can be easily ascertained. Out of many of these, microscopical slides will be prepared for petrographical study, the results of which may be embodied in the next biennial report.

The only map (Plate XVII); accompanying this report is a stratigraphical map representing a protracted section extending from the Connecticut River on the east through the pre-Cambrian and Ordovician terranes to the pre-Cambrian schists on the west. Its original trend is to the northwest nearly at right angles with the average strike of these northeastern formations, N. 40° East.

A marked unconformity of bedding and cleavage planes is occasionally found, as on the south side of Kirby Mountain, therefore the cleavage lines in the section may or may not conform with the planes of bedding. The bibliography, a large part of which appeared in the Third Annual Report of the State Geologist, 1901-1902, is here repeated, because it contains many new references to articles upon the geology of this or kindred areas.

I wish also to recognize my indebtedness to Prof. C. H. Hitchcock of Dartmouth College for suggestions offered and instruments loaned in the summer of 1904 and 1905 ; to Dr. George P. Merrill, Curator of the National Museum, Washington, D. C., for assistance in the identification of a part of the irruptives ; to Dr. George Otis Smith, United States Geological Survey, Washington, D. C., for timely suggestions ; and to the Geological Faculty of Johns Hopkins University for their kindly assistance in many ways.

BIBLIOGRAPHY.

1841. Final Report on the Geology of Massachusetts ; Mica Schist with beds of Limestone.—Edward Hitchcock.

1842. History of Vermont, Natural, Civil, Statistical, with Appendix upon the Geology of Vermont, pp. 222, 223. Limestone with Argillaceous Slate.—Zadoc Thompson.

1845. First Annual Report of the Geology of the State of Vermont, pp. 15, 49, 62. (Mica Slate Limestone.)—C. B. Adams.

1846. Second Annual Report of the Geology of the State of Vermont, pp. 104, 105, 110, 180, 209. Calcareo-Mica Slate, Clay Slate, Talcose Slate, Hornblende Slate.—C. B. Adams.

1846.—A Manuscript Map ; Calcareo-mica Slate.—C. B.

Adams. American Journal of Science, II Series, Vol. I., p. 435. Calcareo-mica Slate.—C. B. Adams.

1847. Third Annual Report on the Geology of Vermont, pp. 17, 18, 24, 29, 30. Calcareo-mica Slate.—C. B. Adams. Geological Survey of Canada. A Geological and Mineralogical Description of the Eastern Townships. Gaspe Slate.—W. E. Logan.

1848. Fourth Annual Report of the Geological Survey of Vermont. Calcareo-mica Slate.—C. B. Adams. Geography and Geology of Vermont, pp. 44, 45, 188, 189. Calcareo-mica Slate.—Zadoc Thompson.

1855. Esquisse Geologique du Canada, accompanied by a geological map of British North America to illustrate the extensive collections of rocks and minerals at the Paris Exposition. Niagara Limestone.—T. Sterry Hunt.

1856. Preliminary Report of the Natural History of Vermont, Appendix, p. 76. Calcareo-mica Slate.—Augustus Young.

1857. Report on the Geological Survey of the State of Vermont. Calcareo-mica Slate.—Edward Hitchcock.

1858. Proceedings of the Boston Society of Natural History. Calcareo-mica Slate.—C. H. Hitchcock. Second Annual Report of the Geological Survey of Vermont, p. 10. Calciferous Mica Schist.—Edward Hitchcock.

1859. Geological Map published in connection with H. F. Walling's topographical map of Vermont. Mica-slate Schist.—A. D. Hagar.

1861. Geology of Vermont. Calciferous Mica Schist.—Edward and C. H. Hitchcock. Map of Final Report. Calciferous Mica Schist.—C. H. Hitchcock.

1862. Letter to Joachim Barrande on the Taconic Rocks of Vermont and Canada. Lower Taconic (Cambrian).—Jules Marcou. Proceedings of the Boston Society of Natural History, Vol. VII, pp. 327, 369; Vol. VIII, p. 239. Calciferous Mica Schist.—C. H. Hitchcock.

1863. Geological Survey of Canada, with Atlas, pp. 431, 432. Gaspe Slates and Limestones (Upper Silurian).—W. E. Logan.

1865. Monograph of the Graptolitidæ of the Quebec Group. Decade II, Niagara.—James Hall.

1866. Geological Map of Canada. Gaspe Slates and Limestones.—W. E. Logan.

1867. The Geology of Vermont. Papers before the A. A. A. S. Calciferous Mica Schist.—C. H. Hitchcock. Manual of Geology, Third Edition, p. 221. Niagara.—James D. Dana.

1869. First Annual Report on the Geology and Mineralogy of New Hampshire, p. 21. Calciferous Mica Schist.—C. H. Hitchcock.

1870. Second Annual Report on the Geology and Mineralogy of New Hampshire, p. 17. Calciferous Mica Schist.—C. H. Hitchcock. The Geology of Northern New England. Paragraph 12 under Geology of Vermont. Calciferous Mica Schist.—C. H. Hitchcock.

1871. Walling's Official Atlas of Massachusetts. Geological sketch p. 20. Calciferous Mica Schist.—C. H. Hitchcock.

1872. Report on the Geology and Mineralogy of New Hampshire, p. 7. Calciferous Mica Schist.—C. H. Hitchcock. Paper before the A. A. A. S. Explanations of a New Geological Map of New Hampshire. Calciferous Mica Schist.—C. H. Hitchcock.

1873. Proceedings of the Boston Society of Natural History, p. 4. Calciferous Mica Schist.—C. H. Hitchcock. Relations of Geology and Agriculture. Report of the Board of Agriculture of New Hampshire. Calciferous Mica Schist.—C. H. Hitchcock.

1874. American Journal of Science. Calciferous Mica Schist.—C. H. Hitchcock. Twenty-seventh Annual Report on New York State Museum of Natural History, by Regents of the University. Distribution of Niagara Group. Niagara.—James Hall.

1877. Topography and Geology of New Hampshire. State Atlas of Comstock and Kline. Calciferous Mica Schist.—C. H. Hitchcock. Geology of New Hampshire, Vol. II, p. 395. Calciferous Mica Schist.—C. H. Hitchcock.

1878. Geological Survey of Canada, part A. Silurian.—A. R. C. Selwyn.

1879. Geology of New England. McFarland's American Geological Railway Guide. Calciferous Mica Schist.—C. H. Hitchcock.

1880. Geological Survey of Canada. Silurian. A. R. C. Selwyn.

1881. Geological Map of the United States. Calciferous Mica Schist. (Lower Silurian).—C. H. Hitchcock.

1883. Geological Survey of Canada, 1880-81-82, part A 4-7. Slates Silurian. Mica Schists Huronian.—A. R. C. Selwyn.

1884. A Dictionary of Altitudes. Bulletin No. 5, United States Geological Survey.—Henry Gannett. Geological Sections across Vermont and New Hampshire, with map showing lines of the sections. Bulletin of the American Museum of Natural History. Calciferous Mica Schist.—C. H. Hitchcock. Geological Sections across Vermont and New Hampshire in New Hampshire Agriculture.—Calciferous Mica Schist. C. H. Hitchcock.

1886. Geological Survey of Canada, Vol. II, part A, p. 29. Niagara (Upper Silurian),—A. R. C. Selwyn. Geological Survey of Canada, Vol. II, part J. Silurian.—R. W. Ells.

1887. Geological Survey of Canada, 47 K. Lower Trenton, (Lower Silurian).—Charles Lapworth.

1890. Revised Edition of McFarland's American Geological Guide. Calciferous Mica Schist.—C. H. Hitchcock. American Journal of Science, Vol. XXXIX, 3rd Series, 1890, pp. 101-115. Review of Dr. Ells Second Report on the Quebec Group.—C. D. Walcott.

1891. A Dictionary of Altitudes. Bulletin No. 76, United States Geological Survey.—Henry Gannett. Correlation Papers. Bulletin 81, United States Geological Survey. The Cambrian Group of Rocks in North America. C. D. Walcott.

1892. Geology of the Green Mountain Area in Massachusetts. Hawley Sheet. Privately printed. Goshen and Conway Schists. (Upper Silurian).

1895. Paleozoic Terranes in the Connecticut Valley. Calciferous Mica Schist.—C. H. Hitchcock. Manual of Geology, Fourth Edition. Niagara.—James D. Dana. A Mineralogical Lexicon. Published as a bulletin of the United States Geological Survey, No. 126. Goshen and Conway Schists.—B. K. Emerson. Geological Survey of Canada. Map. Montreal Sheet. Trenton and Black River (Lower Silurian).—George M. Dawson. Pre-Cambrian Rocks in the Green Mountains. Sixteenth Annual Report, United States Geological Survey.—C. R. Van Hise.

1896. Annual Report of the Geological Survey of Canada, Vol. VII, Lower Trenton (Lower Silurian). Catalog 1896.—George M. Dawson.

1897. Geological Survey of Canada, New Series, Vol. X, part J, p. 20.—R. Chalmers.

1898. The Calciferous Mica Schist and its associated Terranes. A thesis of 177 pages, 44 photographs, 6 drawings and 3 maps, in the library of Dartmouth College. Lower Trenton. —C. H. Richardson. The Washington Limestone in Vermont. Proceedings of the American Association for the Advancement of Science, Boston Meeting, XLVII, Lower Trenton.—C. H. Richardson. Report on the Marble, Slate and Granite Industries of Vermont.—G. H. Perkins. Analysis of Washington Marble with notes upon Distribution and Age in the last mentioned Report. Lower Trenton.—C. H. Richardson. Geological Atlas of the United States, Holyoke Folio, No. 50. Silurian.—B. K. Emerson.

1899. A Dictionary of Altitudes. Bulletin No. 160, United States Geological Survey.—Henry Gannett.

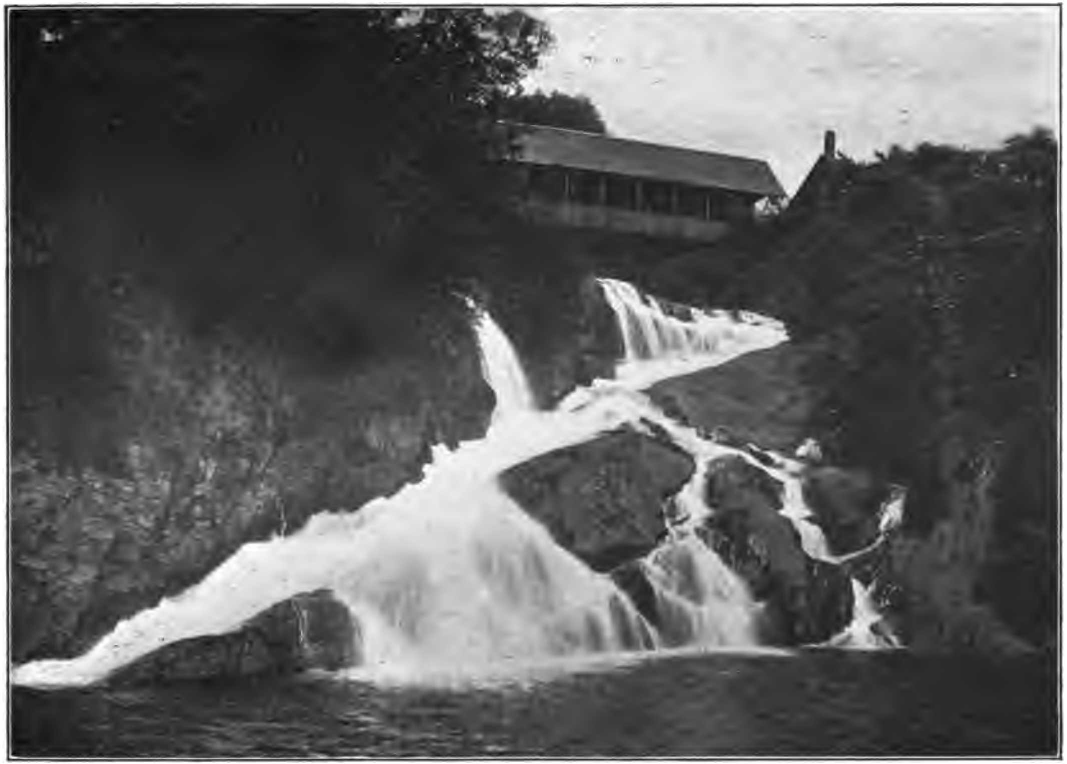
1900. Report of the State Geologist on the Mineral Resources of Vermont.—G. H. Perkins.

1902. Third Report of the State Geologist on the Mineral Industries and Geology of Certain Areas of Vermont.—G. H. Perkins. The Terranes of Orange County, Vermont, included in the above Report. Also published as a separate pamphlet. Lower Trenton.—C. H. Richardson.

1903. Geology of Ascutney Mountain. Bulletin No. 209, United States Geological Survey. Lower Trenton.—R. A. Daly.

1904. Fourth Report of the State Geologist on the Mineral

PLATE XVIII.



Barnet Falls.

Industries and Geology of Certain Areas of Vermont.—G. H. Perkins.

1905. The Geology of Littleton, New Hampshire.—C. H. Hitchcock.

1906. A Dictionary of Altitudes. Bulletin No. 274, United States Geological Survey.—Henry Gannett.

RAILROADS.

Six railroads pass through the narrow valleys of Northeastern Vermont. The Montpelier and Wells River Road operating between the two points named follows the transverse valley of the Wells River, passes between the Blue Mountain granite in Ryegate and the Groton granite, thence through a most excellent timber land over a large area of granite in Marshfield in Washington County to Montpelier. It is also a natural outlet for the Barre granite.

The St. Johnsbury and Lake Champlain Road, extending from Lunenburg on the east to Maquam on the west, is the great outlet for the Woodbury and Hardwick granite of Washington County, and the Kirby granite of Caledonia County, also the lumber in an extensive area on Kirby, Waterford, and Miles Mountains.

The Boston and Maine Road, Passumpsic Division, winding its way up the Connecticut and Passumpsic River Valleys from White River Junction to Newport, its northern terminus within the State, not only affords connection with Montreal and Sherbrooke, its northern terminus in Canada, but it is also the outlet of the Barton, Salem, and Newport granite.

The Grand Trunk Road entering the State from the east at Brunswick passes through a densely wooded section over a granitic area through Brighton, Morgan, and Norton into Canada.

The Maine Central Road only skirts the northeastern corner of the State in Lemington and Canaan, and does not, like the preceding roads, pass through a densely wooded section or over a granitic area.

In addition to these five roads the Hardwick and Woodbury Road should be mentioned. This is a branch owned and operated by the Woodbury Granite Company for the hauling of its large output of granite from the quarries on Woodbury Mountain to the village of Hardwick where it is manufactured. The granite industry is the basis of the economic life of several towns. This is especially true of Hardwick and South Ryegate. Without it hundreds of people now earning their daily bread in the quarries or stone sheds would be engaged in other industry, the railroads would lose a large portion of their valuable freight profits, and the State a large part of its productive resources.

DRAINAGE.

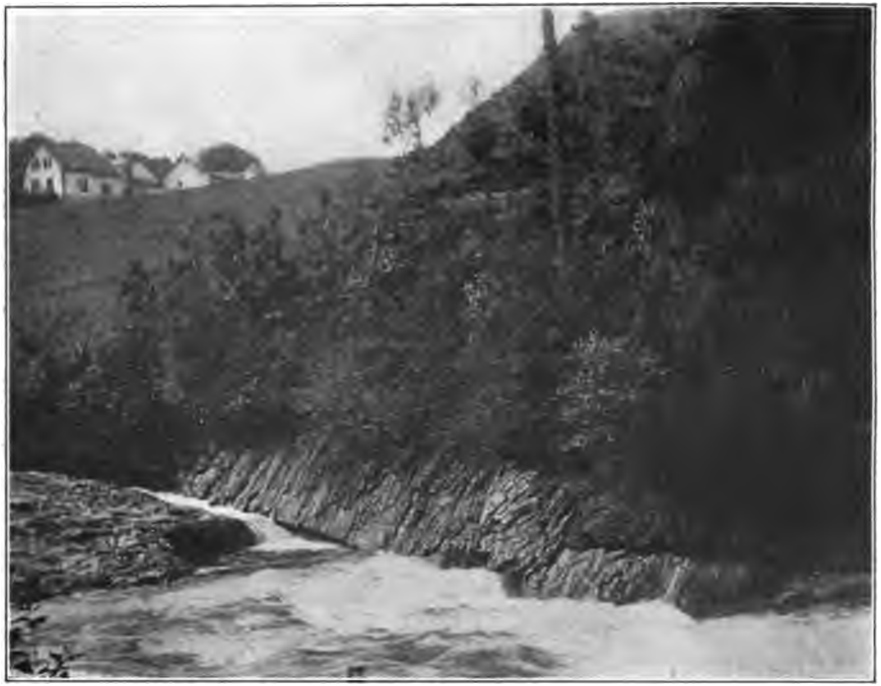
The drainage of Northeastern Vermont is toward the four cardinal points of the compass. The height of land lies from twenty to twenty-five miles south of the International boundary. The general line of high altitude passes through Newark, Sutton, and Craftsbury. To the north the drainage is through the Black, Barton, and Clyde Rivers. Each at Newport flows into Lake Memphremagog, ultimately by the St. Lawrence River reaching the ocean.

The eastern area in Essex County is drained by a large number of rapid streams flowing in a southeasterly direction into the Connecticut. Of these the Nulhegan is the best representative. Plate XVIII represents Barnet Falls at Barnet, Vermont.

The Passumpsic River on the south receives from the east Moose River and from the west Sleeper River then flows almost due south through a deep valley of incision bearing the same name into the Connecticut, thence into the Atlantic by Long Island Sound. Plate XIX represents Passumpsic Falls showing dip of schists to the east. Plate XX represents the Passumpsic Valley looking south below St. Johnsbury. Plate XXII represents Sleeper River Falls in Washington limestone, St. Johnsbury.

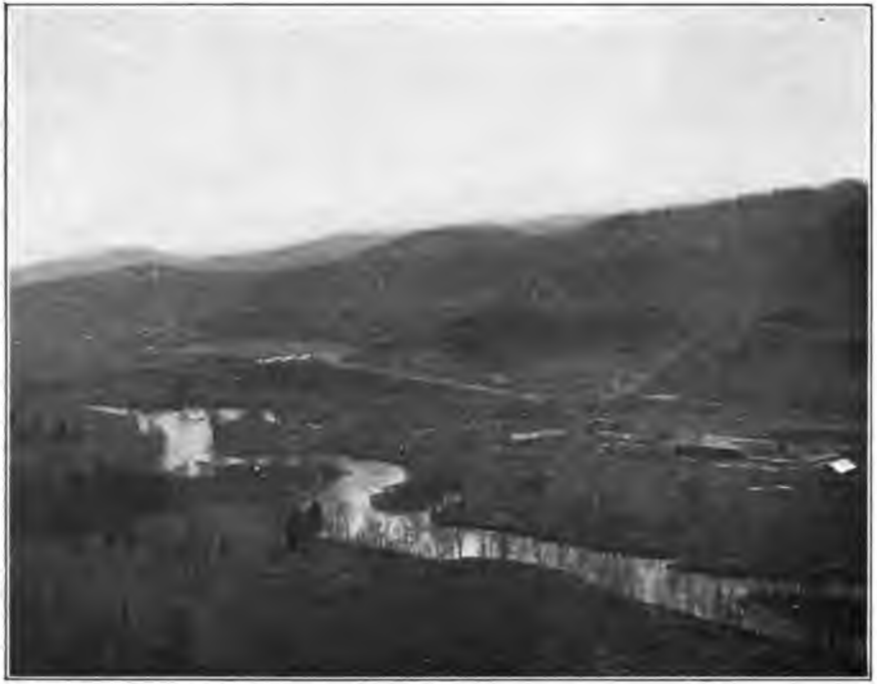
The western area furnishes the head waters of the Lamoille River which flows northwesterly through a deep valley cut through the pre-Cambrian schists and Green Mountain gneiss,

PLATE XIX.



Passumpsic Falls showing high dip of Phyllite Schist to the East, Passumpsic, Vt.

PLATE XX.



Passumpsic Valley looking south below St. Johnsbury, Vt.

across the axis of the Green Mountains into Lake Champlain; thence through Richelieu River into the St. Lawrence.

TOPOGRAPHY.

The area traversed lies between parallels 44° 15' and 45° north latitude, and longitude 71° 30' and 72° 30' west from Greenwich. It comprises an area of nearly 3,000 square miles. Its valleys are both longitudinal and transverse — true valleys of incision. A beautiful illustration of such longitudinal valleys can be found in Woodbury extending along the Gulf Road south from Hardwick, directly west of Woodbury Mountain; the other to the north of Hardwick along the line of the erosional unconformity between the Lower Trenton limestone and the pre-Cambrian schists. The Lamoille River flows to the northwest from Hardwick through a transverse valley cutting across the axis of the Green Mountains. Burke Mountain and Wheelock Mountain in the north may mark somewhat the altitude of an old peneplane and are therefore measuring rods of erosion not unlike Mt. Ascutney in Windsor and Mt. Monadnock in southwestern New Hampshire. Most certainly there is a suggestive similarity in the altitude of these four mountains as found in the table of altitudes in a subsequent portion of this report. Prof. W. M. Davis of Harvard makes the Schooly peneplane the highest in New England representing an altitude of 1,800 feet which is approximately the altitude of the crest of the great anticline that traverses the center of the Waits River limestone.

The limestone being less resistant to the atmospheric agencies than the staurolites of Wheelock, Stannard, and Cabot, affords the deepest valleys. One limestone valley lies to the east of the Green Mountain axis and parallel with it, while another lies to the west of the pre-Cambrian terranes on the east. Its general topography might be suggested by a series of anticlines and synclines with a northeast trend in which the valleys are the synclinal troughs and the hills the anticlinal arches. The stratigraphical section, Plate XVII, gives abundant evidence of this undulation.

ALTITUDES.

An interesting and instructive series of altitudes has been observed not only along the lines of the railroads but upon mountain crests. Those along the railroads show variations in topography as affecting passenger and freight traffic. The following list has been arranged for the Montpelier & Wells River, and the St. Johnsbury & Lake Champlain Railroads from east to west; Boston & Maine, and Maine Central Railroads from the southern point within the area to the northern terminus within the State.

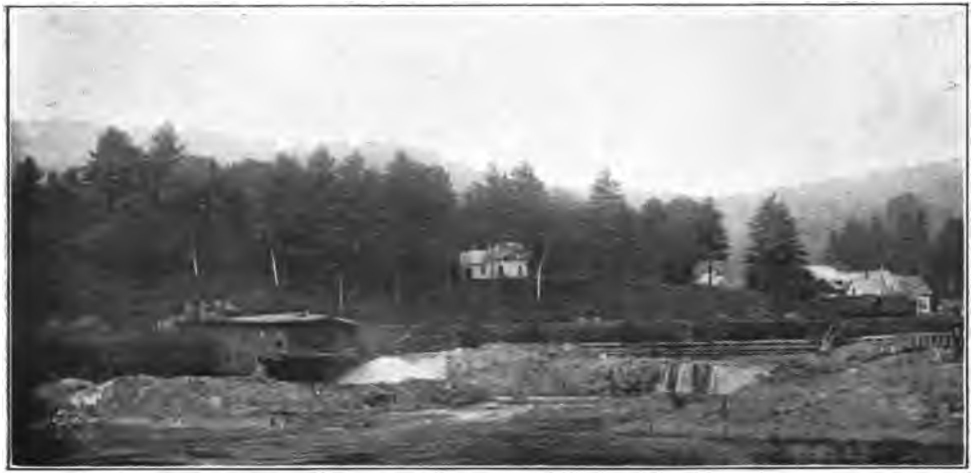
MONTPELIER AND WELLS RIVER RAILROAD.

Wells River	435
Boltonville	624
South Ryegate	724
Groton	773
Groton Pond	1094
Marshfield	1140
Plainfield	752
Montpelier	484

ST. JOHNSBURY AND LAKE CHAMPLAIN RAILROAD.

Lunenburg	844
East Concord	876
Miles Pond	1016
North Concord	1091
West Concord	876
East St. Johnsbury	786
St. Johnsbury	557
Danville	1341
West Danville	1496
Walden	1656
Dow	1411
Greensboro	1146
East Hardwick	1031
Hardwick	861
Wolcott	690

PLATE XXI.



Passumpsic Rapids flowing over the edges of closely folded schists, Barnet, Vt.

BOSTON & MAINE RAILROAD, PASSUMPSIC DIVISION NORTH FROM WELLS RIVER.

Wells River	435
Ryegate	464
McIndoes Falls	441
Barnet	452
St. Johnsbury	557
Lyndonville	727
Barton	945
Newport	688
Derby Line	1042

MAINE CENTRAL RAILROAD.

Guildhall	874
Beecher's Falls	1093

GRAND TRUNK RAILROAD WITH A SINGLE OBSERVATION AT

Island Pond	1178

OTHER ALTITUDES.

Canaan	1053
Leach Pond	1760
Big Averill	1963
Little Averill	2093
Salem Mountain, limestone	1275
Salem Mountain, granite	1410
Willoughby Lake	1062
Willoughby Mountain	2654
Round Top, Victory	2200
Miles Mountain, Concord	2470
Blodgett Mountain, Stannard	2500
Wheelock Mountain, Wheelock	3000
Burke Mountain, Burke	3277
Ascutney, Windsor	3220
Monadnock, Jefferson, N. H	3181

GLACIATION.

Glaciation is a potent factor in the topography of the area, therefore it falls within the scope of the present report. The subject has been so thoroughly discussed by Prof. C. H. Hitchcock in the Fourth Report of the Vermont State Geologist 1903-04, that I will only briefly consider the matter. The depth of the ice mantle as it moved down from the Laurentide Hills must have been 5,000 feet, for the five highest mountains of Vermont, all over 4,000 feet, are glaciated to their very summits.

In October, 1897, in company with Dr. Hitchcock, the author spent some time in collecting Lower Trenton graptolites at Castle Brook, Magog, Quebec, and in quest of glacial evidences on Mt. Orford.

We did not content ourselves with the study of the mere foothills of this classic mountain. From the southwest side we ascended to the very summit, and within ten feet of the highest point we found a fine bowlder of Laurentian gneiss. A section of this erratic was sent to Prof. F. D. Adams, of McGill University, and this eminent authority was satisfied that the wanderer was Laurentian gneiss from the north side of the St. Lawrence.

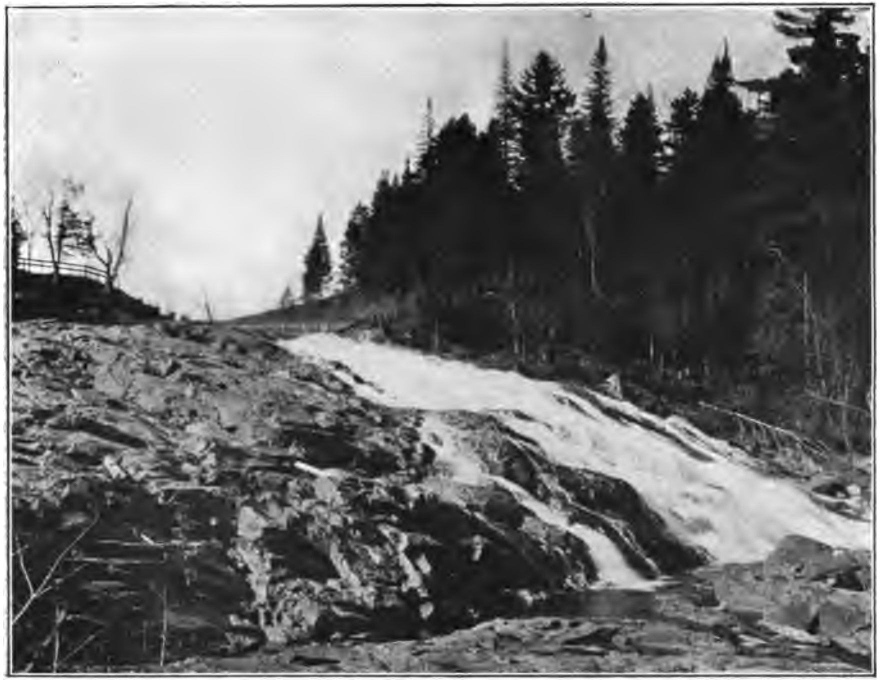
I left Prof. Hitchcock at the flagstaff and went down quite a distance on the north side of the mountain, and at all altitudes found bowlders of metamorphosed sediments and irruptives, which argue in favor of the glaciation of Mt. Orford.

In the summer of 1904 I visited Owls Head finding kindred evidences of glaciation to its very summit. I have also found erratics of Laurentian gneiss in Vermont, fifty miles below the International Boundary at altitudes of over 2,000 feet amidst quartz veins beautifully polished and striated.

No principle of glacial geology seems more firmly established than that erratics pass from lower to higher altitudes. Dr. Bell states specifically in his "Glacial Phenomena in Canada" in Vol. I, Bulletin of the Geological Society of America, that Laurentian bowlders were transported from the comparative low region north of the Georgian Bay to tablelands of much higher altitudes. Tyrrell in his "*Glaciation of North Central Canada*," Vol. VI of the Journal of Geology brings out the same facts.

The author has camped upon many mountains in Vermont

PLATE XXII.



Sleeper River Falls, St. Johnsbury, Vt.

and most of the highest peaks in New Hampshire. Abundant evidence that these crests were ice covered exists upon them all. Therefore not a nunatak remained in all New England save Mt. Katadin, the majestic sentinel of Maine, due to the natural thinning out of the ice sheet towards its edges. The ice that overrode all the mountains of Vermont and New Hampshire, even the dignified Washington with height of 6,293 feet, came therefore from the low region to the north.

The general trend of the ice was southeasterly. Its direction may be traced not only by the striae upon rocks stoutly resisting disintegration and erosion but by erratics.

Another striking illustration is the large bowlder of peculiar concretionary granite transported over Wheelock Mountain from the village of Craftsbury, now standing sentinel in a door yard one mile below South Wheelock. The longitudinal and transverse valleys have both been deepened and broadened, outlets of valleys obstructed, and numerous placid lakes remain. A mantle of debris therefore covers the entire field save here and there on the stoss side where the preglacial soil has all been removed. A local terminal morain crosses the State in a westerly trend in the neighborhood of Lyndon and St. Johnsbury. The high terraces of the Passumpsic valley rising hundreds of feet above the river bed at Lyndon Center and St. Johnsbury give some evidence of the vast amount of morainic material thus deposited at this temporary lower limit of the ice and modified by the flooded rivers. Another section impeding progress in field work is in Concord and Lunenburg where the pre-Cambrian terranes are completely covered with a mantle of erratics. Around Lake Memphremagog where the planes of bedding and cleavage coincide and the rock is less highly metamorphosed, the mantle of glacial debris obscures the rock masses and thereby may prevent the discovery of the true diagnostic features of age.

LAKES.

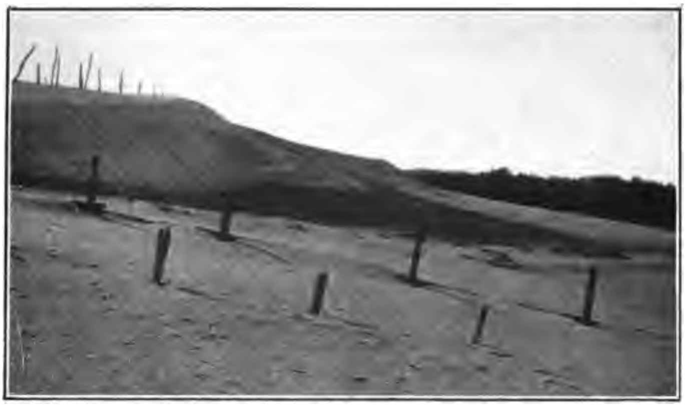
The chapter upon topography would be incomplete without some reference to the scenic beauty and economic significance of numerous lakes. Scarcely a town exists within the area that is not studded here and there with these placid, transparent sheets of water. Mention will be made of only a few of those that have become important summer resorts thus bringing a certain amount of trade within the borders of the State, or perhaps more important than all, have become an inexhaustible source of power. Their origin is glacial. The valleys have been deepened by the scouring action of the ice. The original outlets of many valleys of incision were filled with glacial debris and the small outlets sought new channels.

ORLEANS COUNTY.

Lake Memphremagog at an altitude of 686 feet extends from Newport, Vermont, to Magog, Province of Quebec, a distance of thirty miles. It is estimated to cover an area of 48,000 acres of which 9,600 are in Vermont. Its scenery is unsurpassed in beauty. Its highest wall is Owl's Head, rising 2,749 feet above the lake, about two miles north of the lake on the western shore. Its bed is one of limestone and of slate. Practically it lies upon Lower Trenton and Devonian limestones. The former pass under the lake in its southern portion while the latter are found at Owls Head on the west, and Georgeville, Province of Quebec, on the east. A band of Lower Trenton slate interstratified somewhat with the lime falls between the two limestones.

Willoughby Lake in Westmore, six miles east of Barton, at an altitude of 1,c62 feet is unsurpassed in grandeur by any waters of New England, even if by Alpine lakes. Mural precipices rise 1,592 feet above it upon either side. From the crest of Willoughby Mountain 2,654 feet in altitude, it seems to stretch itself in the cardinal direction of north and south, a distance of seven miles. Although it looks like a narrow line it averages nearly a mile in width and covers about 3,840 acres. Its bed is in Waits River limestone. The origin is three fold. The limestone in Devonian times was broken through by granites upon either side of the lake. The crests of Willoughby Mountain on the east and Mt. Hor on the west stoutly resisted Mesozoic denudation while the intervening limestone easily suffered

PLATE XXIII.



Migrating Sand Dune near St. Johnsbury Center.

solution. It was attacked both by the carbon dioxide of the atmosphere and the sulphuric acid formed in the oxidation of pyrites encased in both sedimentary and intrusive rocks. Upon the invasion of Vermont by the great ice sheet that spread over all of New England its lower portions filled with gravers tools found an easy channel which it immediately began to deepen. The stouter igneous material more easily resisted the ever planing action of these lower layers of ice, while the friable limestones readily gave way to its influence. A considerable pile of glacial debris, now somewhat modified drift, crosses the valley to the south and prevents the flow of its transparent waters into the Passumpsic River. A modified drift traverses the broader valley to the north which contains the outlet of the lake. Thus disintegration, solution, abrasion, and gravel building, has each aided in giving Willoughby Lake a depth exceeding 500 feet. Soundings have been made at 450 feet striking bottom but at the greater depth the bottom was not reached. Unexpectedly the shallow portions of the lake are without bowlders. In water of considerable depth the floor is seen covered with a fine white sand, resulting from the disintegration of the granite, showing perfectly uniform ripple marks as if made by the action of tides on the Atlantic Coast.

Barton Lake, in the village of Barton River, skirts the Boston & Maine Railroad for three miles and covers an area of 800 acres.

Derby Lake in Derby, although much smaller, covering only about 75 acres, is scarcely less beautiful.

Caspian Lake at an altitude of about 1,750 feet, lies in a bed of limestone. It is situated two and one half miles north of Greensboro Bend in Greensboro and about a three minutes walk from the village. It is impossible to see this lake, covering 2,780 acres, until you stand almost at the water's edge. There are few if any lakes that surpass it in its scenic beauty.

ESSEX COUNTY.

Nestled among the granite hills of the extreme northeastern corner of Vermont are found three lakes. Unlike the five lakes mentioned in Orleans County whose beds are limestone, these are in granite. Their shores are whitened by the granite sands from the disintegration of the surrounding wall rocks. These grains of sand are rounded and polished by the impact of the water. The lakes, surrounded by forests, are thus hidden from view until one comes upon them unexpectedly in the thickets. They are situated on the height of land, whence the waters drain on one side into the St. Lawrence through the Coaticook and St. Francis rivers, and on the other into the Connecticut river through Leach stream, the outlet of the smallest of these bodies of water. Leach pond covers an area of 114 acres at an altitude of 1,800 feet. Big Averill covers an area of 860 acres at an altitude of 1,963 feet. Little Averill covers an area of 1,280 acres at an altitude of 2,093 feet. The divide between the first and second is 2,013 feet and between the second and third 2,150 feet. A ten minutes walk only is required to reach Big Averill from Leach pond while Little Averill lies one mile to the southwest beyond Big Averill. The close proximity of these three lakes to each other, the low divides between them, and their access from the first by trail through the thicket are suggestive and interesting.

Another pond whose bed is in part granite and in part metamorphic schist is found in Concord. It is known as Miles pond lying at the foothills of Miles mountain at an altitude of 1,010 feet.

CALEDONIA COUNTY.

Caledonia County is not without its scenic lakes and ponds. Long Pond in Groton at an altitude of 1,050 feet, covers 2,500 acres. Like the lakes of Essex County its bed is granite. Although there are outcrops of Washington limestone lying near it on the east, there is no positive evidence that the limestone cuts beneath the pond. The area is still largely wooded and the lake furnishes the power for a large lumber industry.

Harvey's Lake in Barnet is 800 feet above sea level. Although it contains no more than 600 acres, yet it is one of the prettiest sheets of water in New England. Its bed is in Waits

PLATE XXIV.

Lowell Mountain from Irasburg, Vt.

River limestone while intrusives of granite lie both to the east and to the west of it thus enhancing its beauty.

Another significant lake is St. Joseph's Lake in Danville and Cabot. It lies in limestone at an altitude of 1,490 feet. The limestone has a slight dip of only 10 to 15 degrees to the west. It must have been formed by the scouring action of the ice together with the greater solubility of that portion of the limestone forming its bed; or by the burying of the original channel of Joe's Brook, which is its outlet, by glacial debris. The present outlet of the lake falls 140 feet in a distance of 1500 feet over sheets of Waits River limestone, thereby furnishing most excellent water power both for cutting lumber and granite.

GEOLOGY.

To unravel the intricate details of the geological structure and diagram the true stratigraphical sequence of these heterogeneous terranes is no easy task. Hon. James Richardson found in 1872 that epidotic, chloritic, and serpentinous rocks with crystalline limestone and magnetites were characteristic of Upper Paleozoic as well as Lower Paleozoic terranes in British Columbia, the Eastern Townships, and New England. The geologist in the field fully realizes the possibility of error amidst these crumpled, folded, faulted, metamorphic rocks. There will exist considerable doubt and uncertainty until some geologist in his good fortune finds the true diagnostic feature in paleontological evidence within the State.

A.

PRE-CAMBRIAN.

This term as here used signifies a group of sedimentary rocks flanking the Waits River limestone on the west, and a lithologically similar group of sedimentary, or meta sedimentary, highly metamorphic rocks on the east.

The western member consisting of chlorite schists, micaceous quartzites, and gneisses, and flanking the Green Mountains on the east has been quite definitely settled as pre-Cambrian. It is this belt that carries the Eden and Lowell serpentine and asbestos deposits. No attempt has been made to determine its structural features save on the border of the limestones. The stratigraphical section is carried from Hardwick toward Wolcott, a distance of six miles until the rock assumes a westerly dip.

The eastern belt lies directly west of the Connecticut River. It stretches across Essex, Caledonia, Orange and Windsor Counties. It reaches a breadth of five to ten miles in Essex County and south of Wells River becomes a narrow band. Occasionally beds of talc and steatite are found within it.
Plate XXIV. Lowell Mountain from Irasburg.

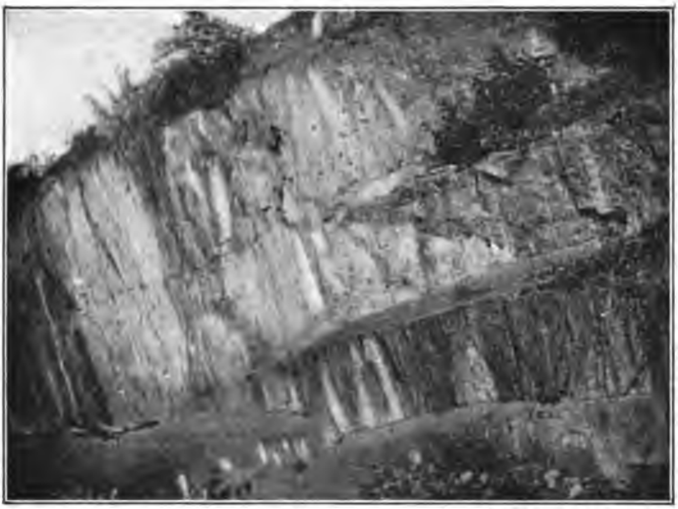
a. Lunenburg Schist.

Lunenburg Schist is the chief pre-Cambrian representative in the eastern belt. Through this the Connecticut River has cut its sinuous channel along the interstate boundary. It is a highly metamorphic, green, greasy, chlorite schist often studded with pyrite. The chloritic phase comprises a belt two miles wide on the eastern slope of the cliffs from Guildhall to Hartland. A most excellent development can be found in Concord and Waterford. Sericites and occasionally phyllites are present in Barnet and Ryegate. At McIndoes Falls the dip of the sericite schist is 85 W. while in Barnet it is slightly to the east. Near the railroad cut below Barnet there is a small area with nearly horizontal position—a purely local character. Plate XXV represents a railroad cut in Lunenburg schist at Wells River.

b. Protogene Gneiss.

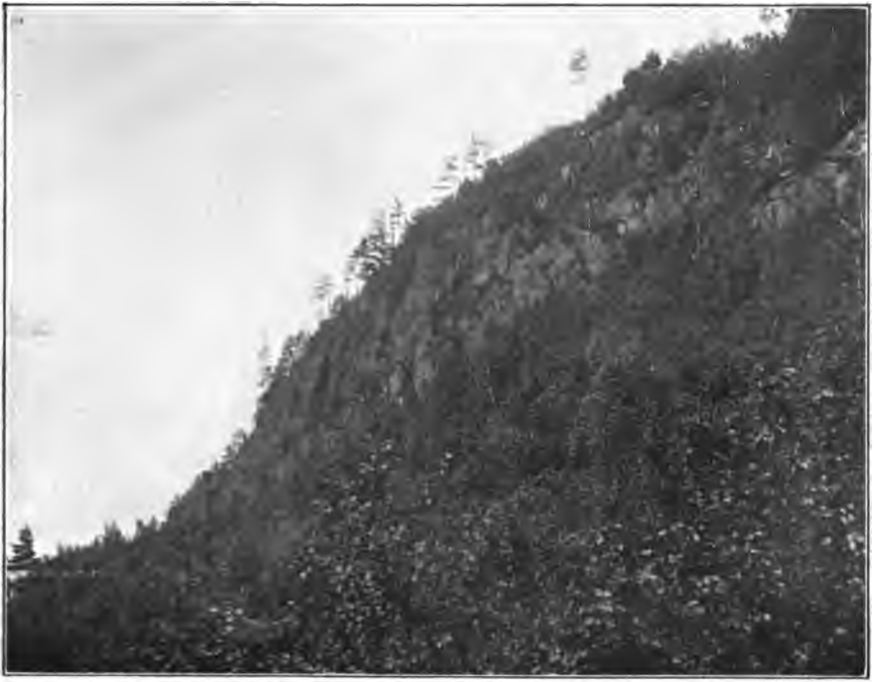
The eastern border of the Lunenburg schist is cut by several outcrops of protogene gneiss. Some of these cliffs rise 200 feet above the Connecticut River where with almost vertical faces they closely resemble the basaltic palisaides of the Hudson. Plate XXVI Barnet Cliff 100 rods along.

PLATE XXV.



Railway Cut in Lunenburg Schist, Wells River, Vt.

PLATE XXVI.



Barnet Cliff, Barnet, Vt.

c. Sheared Quartzite.

Flanking the Lunenburg schist in the west is a narrow belt of sheared quartzite. Two miles northwest from Lower Waterford on the farm of R. W. Remick this phase can be easily seen. Small veins of galena slowly increasing in width and number with descent are found in this member. It is represented in the section as lying above the chloritic schist as in a tightly folded synclinal trough. Its western dip is nearly vertical where it comes in contact with sheared diorite porphyra. A highly quartzose phase appears in Ryegate. When the detailed mapping of Essex County can be taken up, its field relations will be better understood.

Although no fossils have been found in the Lunenburgh schist and in this quartzite in the areas of the least metamorphism yet I am inclined to believe that their true stratigraphical position will be Cambrian.

d. Hornblende schist.

Hornblende Schist is often associated with the sericite. Sometimes it reaches a thickness of 1,000 feet. It often becomes feldspathic and can be catalogued a gneiss. Exact duplicates of specimens of gneiss from Baltimore, Maryland, are easily obtained along the Connecticut River in Orange County where it lies between the gneiss and the Lunenburg schist. The best representative in the northern field is in Barnet. Plate XXVII represents the cleavage plane dip in the hornblende schist in the cliff near East Barnet.

e. Metamorphic Feldspathic Schists.

There is a belt of considerable width in Concord and Waterford of a greenish, feldspathic schistose rock. It has been suggested by Dr. Mathews of Johns Hopkins University that it is a sheared amygdaloid. Every stage of gradation between a diorite porphyra and this highly metamorphic material can be traced in the field, but whether it represents an original feldspathic mica schist, an amygdaloid, or a diorite porphyra, only a large number of microscopical slides can determine. The phenocrysts of feldspar have suffered much decomposition and further study is necessary to determine its exact nature.

Prof. Hitchcock suggested in *Geological sections crossing New Hampshire and Vermont*, the term Montalban as equivalent of the White Mountain series in New Hampshire whose age is designated as upper Laurentian. In this report I have included these with the Lunenburg schist as pre-Cambrian awaiting further field investigation.

Dr. T. Sterry Hunt in 1870 suggested the same name, Montalban, for the terranes now known as the Waits River limestone and the Bradford schist. As the name has been applied to formations separated so widely by degree of metamorphism as well as by age the name is dropped from the present discussion. Some of the important dips in the pre-Cambrian terranes are here catalogued. Metamorphic schist, Concord, St. N. 40° E, dip 80° E.; Waterford, dip 85° E. Sheared Quartzite, dip 90°. In Lower Waterford, Lunenburg schist St. N. 45° E. dip 80° E. One mile west of Concord dip 80° W. Thus the whole series is everywhere tilted to a very high angle closely folded into anticlines and synclines.

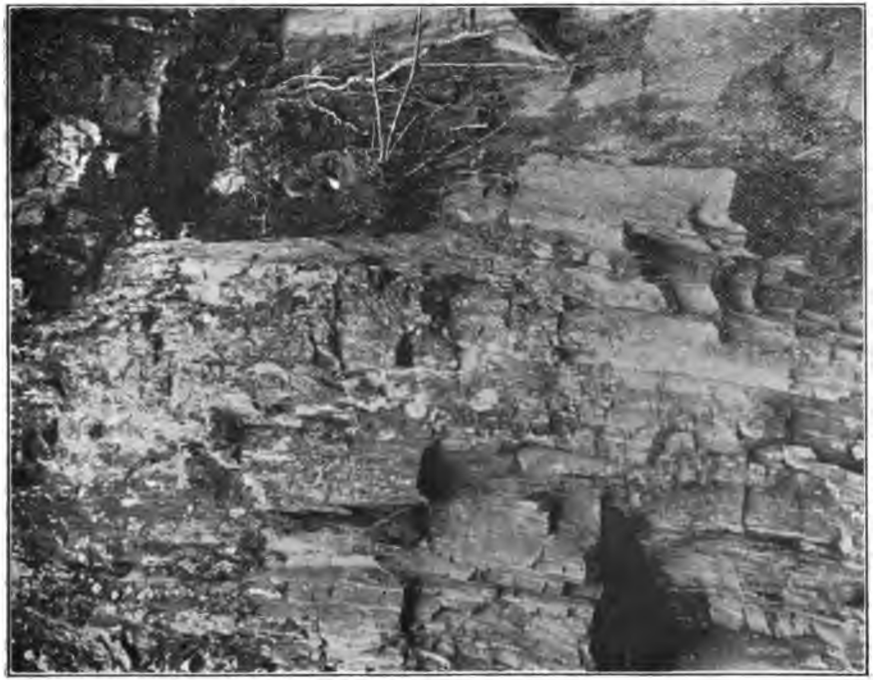
B.

IRASBURG CONGLOMERATE?

Irasburg Conglomerate is so named from the town of Irasburg in Orleans County where it is best represented. The author in the summer of 1904 discovered this conglomerate on the farm of F. A. Willey one half mile below the village of Irasburg on the West Albany road, and visited it again in 1906. The fine exposure is on the left hand side of the road.

Its conglomerate nature is unmistakable. Pebbles of granite are tightly held in the folds of the highly metamorphic micaceous portion. One of these is six inches long and four inches wide. Fragments of diorites, highly metamorphosed schists,

PLATE XXVII.



Hornblende Schist with nearly vertical dip, East Barnet, Vt.

and quartz pebbles, are also present in large numbers and the bands of limestone are interbedded with the more micaceous portions.

The structure of the conglomerate strikingly suggests a rapidly sinking sea upon whose shores these calcareous sands were deposited. As the beds of lime are siliceous and lithologically identical with the Waits River limestone it should both mark the basal member of the Lower Trenton series and the great erosional unconformity on the west. The shore was to the west from whence these pebbles came. It would be a distance of more than fifty miles in a southerly direction to kindred irruptives in the pre-Cambrian terranes to the east of the Waits River limestone. Furthermore the pebbles of granite and its associates are directly traceable to the kindred irruptives in the pre-Cambrian terranes in the west which are separated from the Waits River limestone by an erosional unconformity.

The history then is marked, (1). by a period of deposition in which many thousands of feet of sediments were laid down. The source of the material was the disintegrated portions of the Green Mountains to the west. (2). A period of rise during which these sediments were somewhat folded and brought above the sea level. (3). The introduction of igneous activities when the granite and diorites were intruded into the schists and along their lines of contact added new minerals. (4). A long period of denudation whose time of duration is most difficult to estimate. (5). A period of subsidence upon the margin of whose sinking floor these calcareous sediments were deposited then gradually in deeper, clearer, and more quiet waters the Waits River limestone was formed. (6). A period of rise in which the conglomerate was brought above sea level. (7). The introduction of intrusives into the limestone. (8). The present period of disintegration and erosion.

The general dip is to the west and the strike in a northeasterly direction. Strikes and dips can be taken in many directions owing to the highly folded and crumpled character of the formation. Some fifty rods from this outcrop toward Irasburg the conglomerate appears in much longer exposures on both sides of the brook where once there seemed to stand an old mill. Here samples of good limestone free from pebbles can be easily obtained. Dr. Hitchcock has described a bed of talcose conglomerate in Newport and Coventry, also at Owls Head, Canada, everywhere dipping under the bright green talcose schists apparently with scarcely any planes of stratification. This is flanked on the east by a slate then a limestone that Dr. Hitchcock would call Devonian, and then Montpelier slate.

The stratigraphical position of the Irasburg conglomerate is therefore capable of two interpretations. (1). That it is the basal member of the Waits River limestone formed upon the rapidly subsiding sea floor when the sea transgressed upon the pre-Cambrian schists. (2). That it is the basal member of a younger series of rocks lying in a narrow belt between the Montpelier slate on the east and the pre-Cambrian schists on the west. Comparison of specimens collected in the section crossed would lead one to accept at the present writing the former opinion. Further detailed field investigation is required before this most valuable diagnostic feature can be definitely translated.

Erratics of another coarse conglomerate were found to the east of the Bradford schist in Concord. The pebbles were much flattened by the intense pressure to which they had been subjected and often elongated parallels with the planes of foliation. S. R. Hall in his report relating to geology of northern Vermont, cites such a coarse conglomerate in Granby, Victory, and Concord. Although Hall recognized a similarity between the two, yet to me they are strikingly different. The former conglomerate is decidedly calcareous. The latter is devoid of lime. The former is micaceous and unquestionably sedimentary; the latter is micaceous and meta-granitic. As the former represents the shore line between the Waits River limestone and the pre-Cambrian schists on the west, so the conglomerate on the east may represent the shore line between the Bradford schist and the pre-Cambrian terranes on the east. The removal of the lime for a distance of five to eight miles may explain its utter absence from the latter conglomerate. It is possible then that these two conglomerates mark the border of the great trough in which the Waits River limestone was formed. In the absence of an opportunity to study this conglomerate in situ and in its field relations, I have simply called attention to another diagnostic problem demanding further investigation.

C.

DEVONIAN.

This brief discussion of a possible Devonian problem may or may not fall within the scope of the present report. The rock lies just outside the field of special investigation yet crossed in my recent reconnaissance. Dr. Edward Hitchcock calls attention to a narrow belt of limestone and slate flanking the pre-Cambrian schists on the east of the Green Mountain axis, and extending from Owls Head on the west shore of Lake Memphremagog as far south as Montpelier, Vermont. A thickness of 200 feet is accorded to the limestone in Coventry. It is characterized as a black, carbonaceous, slaty limestone ringing under the blow of the hammer. It has the normal strike of the terranes of northeastern Vermont, and dips invariably to the west, which position can only be explained by a fault or an overthrust.

At Owls Head, a few miles north of the International Boundary, Devonian fossils are beautifully preserved. A careful examination of the character of this formation was made in 1904 in hope of finding it represented within or bordering the Washington limestone, but Devonian fossils were not found in Vermont either east or west of the Lower Trenton slate. A kindred deposit is also found at Georgeville, Province of Quebec, which was likewise examined. An area of thickly wooded glacial drift intervenes between the exposure at Owls Head and Newport, therefore there is great difficulty in proving the continuity of the formation, the planes of cleavage coincide with the apparent planes of bedding. Strange indeed that in a contiguous area where metamorphism is no greater there should be no evidence of fossilization in Newport.

This apparent absence of Devonian characters may be indicative of Lower Trenton age and that the band of limestone is simply a narrow belt of Waits River limestone interstratified with Montpelier slate, which phenomenon is often observed on a smaller scale both at Newport and in Orange County. However, its exact relation is one of the problems that I hope to settle in my next terse report upon Orleans County.

D.

WASHINGTON LIMESTONE.*

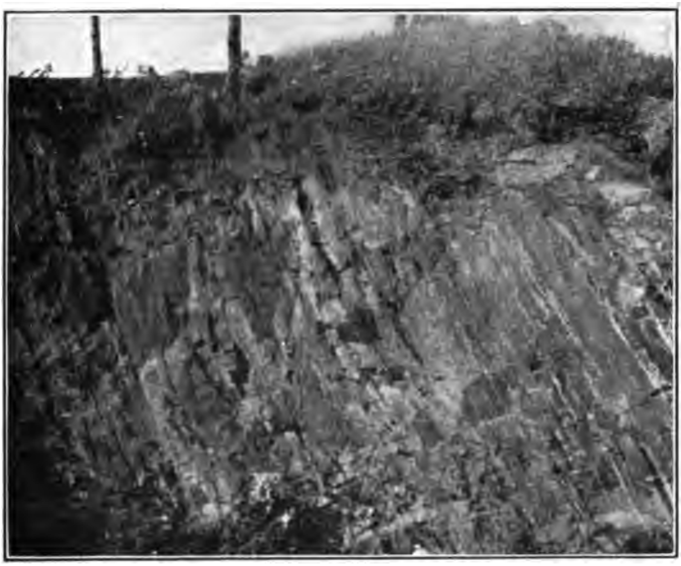
This name the author applied in 1895 to the calcareous member of the calciferous mica schist of previous reports by Prof. C. H. Hitchcock, although the first publication of this term appeared in 1898. The name Washington was chosen because in that town in Orange County the limestone assumes its maximum typical development. Here it is that the strata lie in nearly horizontal position; the texture is uniform, the percentage of lime higher, and the polish which it receives finer than in any other part of the State. It was here also that the discovery was made in 1893 that the rock was sufficiently pure to be used as a marble. In 1898 more than twenty-five quarries had been opened and the demand was in excess of the capacity of sheds, polishers, and the capital invested, to meet the supply. Many of these quarries have been abandoned not from an inferior quality of the stone for monumental and structural purposes, but from poor financial management of the initial movers.

The limestone stretches itself across the entire State from north to south just east of the central line through Northfield and Montpelier. It approximates forty miles in width in Canada where it lies between the east and west division of the Quebec Group. In Hartford it divides by the intervention of the Bradford schist. The western member terminates in Cavendish in Windsor County. The eastern member crosses Windsor and Windham Counties

---

* In this paper the name Washington Limestone has been changed to Waits River Limestone. See note at the end.

PLATE XXVIII.



Limestone interstratified with Slate, Newport, Vt.

and may be the formation in Massachusetts known as the Conway schist.

Three distinct phases of the limestone can be easily recognized in the field. The first is a beautifully banded variety closely resembling the Columbian marble of Rutland, Vermont. The typical development of this variegated variety is found at Waits River, Vermont, where it was quarried in 1897-99 by W. M. Carnes and Company, and advertised as "Vermont Imperial Variegated Granite." This banded phase crops out again in Danville and in Westmore. Small, yellowish brown crystals of phlogopite are scattered through it with orientation parallel with the planes of bedding. At the foot of the cliff at the base of Mt. Hor in Westmore this feature is well illustrated. Here the strata lie in a nearly horizontal position though dipping at a few degrees to the west.

The second phase is a dark steel gray silicious limestone sometimes banded in appearance but more often fairly uniform in color. The darkest and purest portions of this variety are found in Washington and in Danville. In Washington large blocks can be secured perfectly uniform in color without seam or flaw, and in Danville it presents the same aspects though in a less marked degree. In the village of Danville by the roadside leading to the station is a typical outcrop of this variety. In Derby and Newport it becomes much lighter in color, and in Canada a very light gray in many localities. On the east it becomes a lighter gray and passes into the Waits River phase. On the west the rock holds its fairly uniform texture as can be seen in Craftsbury, Hardwick and Walden. This variety is susceptible of the highest polish and takes a lettering legible to a greater distance than any other known rock. This is especially true when the face of the letters with their polished surfaces stand out in bold relief from the white hammered background.

The third phase is a dark carbonaceous variety of more shaly texture and never susceptible of a fine polish. It graduates by almost insensible gradations into the dark steel gray variety yet in many cases there is quite a rapid transition from one to the other. This variety is the uppermost member, for it flanks the steel gray variety upon the east and the west. On the east in St. Johnsbury along the Boston and Maine Railroad below the village beautiful illustrations of the dark variety can be observed and on the west in Albany, Irasburg, and Newport. This phase assumes a more nearly vertical position until it is intimately interstratified with slates and shales that overlie the Washington limestone. Plate XXVIII represents such interstratification at Newport.

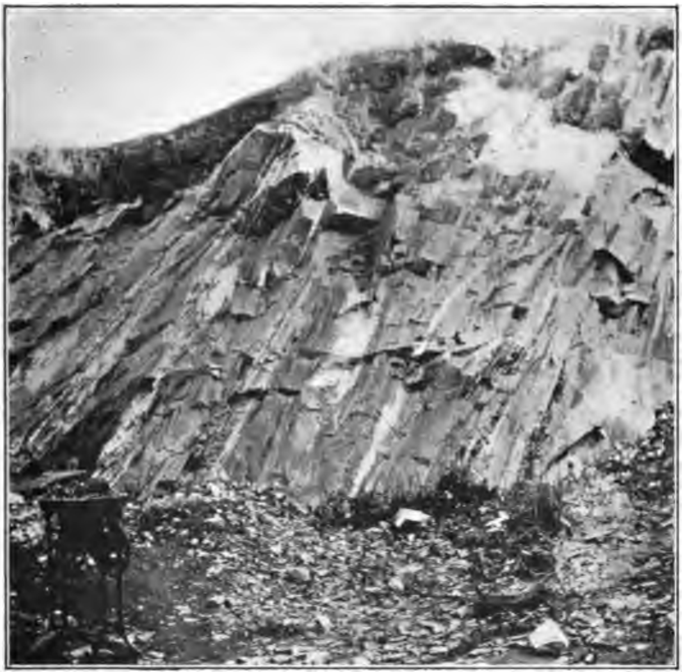
A few special phases, apparently local in character, are worthy of recognition. One of these is about one mile south of South Walden Post Office where the rock becomes very arenaceous with great fissility along vertical planes and in which there are some suggestions of fossils. It is an area demanding further investigation along that line.

A second localization presents itself in Irasburg about one mile east of the village on the road to Glover. Here the limestone assumes a dark brown color, nearly a vertical position and becomes more shaly than at any other point investigated. Here also fractured portions of the fragile limestone seem to imitate organic forms. The locality may well be marked as one worthy of further search for diagnostic features.

At a third locality it is entirely different in type and character. It is located in Westmore on the south side of Willoughby Lake. It is the brecciated phase of the Waits River limestone —purely local in effect. Such limestone breccias were not supposed to exist on the east of the Green Mountain axis and the discovery in Westmore is attended with no little interest. Many fragments were found at the base of the perpendicular cliffs. The fragments of the dark gray limestone are sharp and angular, showing no appearance of the rounding processes. These are cemented together by crystals of pure white and yellowish-white calcite. The source of the lime is from the shattered limestone rock. The fracturing was done by the numerous intrusives cutting their way through the limestone. These will be noticed later as bosses and stocks of granite, dikes of diabase of the camptonite order, and amygdaloids.

The Waits River limestone as a unit is interstratified with

PLATE XXIX.



Easterly Dip of Limestone near St. Johnsbury, Vt.

numerous beds of phyllite schist. Daley says in his Geology of Mt. Ascutney, "The limestone is in the phyllite series." The converse in reality is true for the limestone predominates in the areas described. The interstratified phyllite often becomes black and plumbaginous from the graphite disseminated through it. This is well illustrated at the John Guyer quarry on Observatory Knob, St. Johnsbury.

A single hand specimen shows distinctly thirteen faults in the graphitic phyllite schist. In the same vicinity it often becomes ottrelitic from hexagonal scales of ottrellite set transverse to the planes of foliation. This often becomes so tough and compact that it is catalogued as hornblende. This mineral has developed in the limestone in many places, perhaps best observed in Barnet. Staurolites, and incipient iron garnets are common in the bands of phyllite.

The limestone underlies the Bradford schist which will be described in E, the next division of this report. On the east through Barnet, Burke, and St. Johnsbury its inferior position is distinctly noticeable. At St. Johnsbury on Observatory Knob its easterly dip is clearly seen at an angle of 45 degrees. Plate XXIX.

In Danville there are three distinct cuts made in the Waits River limestone by the St. Johnsbury and Lake Champlain Railroad. The first of these is known as Badger Gap 300 feet long and estimated 40 feet high. Here the limestone lies with a low dip of 15 degrees to the east. The strike is normal to the area, N. 30 E. The strata is cut with numerous quartz veins, highly folded, sometimes parallel with the bedding, often crossing the bedding planes at all angles.

The second is known as Crane Ledge about one mile east of Danville. It is 600 feet long and reaches a maximum depth of twenty feet. The sheets are nearly horizontal, practically the crest of one great anticline yet there are many apparent foldings in the limestone. One interesting feature within the cut is the presence of an intrusive. A dike of camptonite varying from three to five feet crosses it in a northwesterly direction. It is somewhat concretionary in its decomposition and presents most beautiful slickensides.

The third cut is a few rods east of West Danville. It is not as large as the other two but marks the western slope of the anticline.

Plate XXX shows the nearly horizontal position of the strata.

This anticline which is so well represented in Danville traverses the entire limestone formation. Its position in Washington is equally well represented. In Marshfield and Peacham it is broken through by a large mass of granite, so that upon the east in Peacham the rock dips to the east and on the west in Marshfield the rock assumes the westerly position. This northeasterly trend carries the anticline through Sutton where good exposures of the limestone can be observed. Nearer the International Boundary it is broken through again by irruptives especially by the large granitic area in Holland and Norton. In general a synclinal fold can be traced between the anticline and the Montpelier slate on the west. The coincidence of the planes of cleavage and the planes of bedding would lead to the conclusion that the cleavage was developed prior to the folding. The arenaceous character of the limestone would indicate an Ordovician sea of some considerable depth. The fine grains of silica may have come from the disintegration of sandstone of Cambrian age and unconsolidated sands of even later age. The lime was largely derived from organic remains yet in part it may have been the results of chemical precipitation.

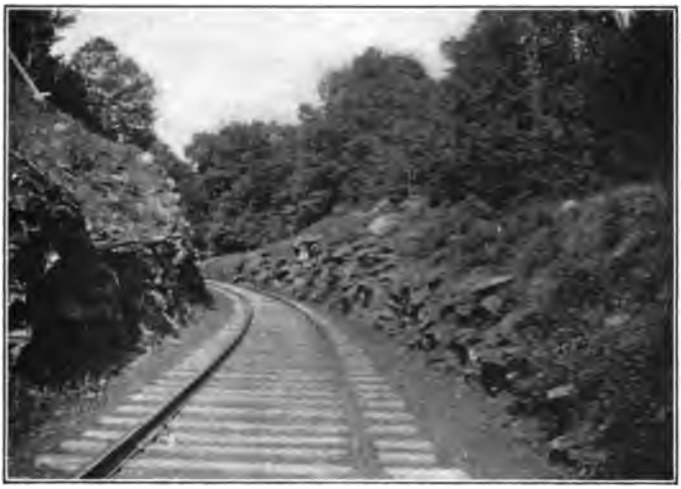
The presence of the beds of phyllite so often interstratified with the lime may represent varying conditions either in the sea or on adjacent land masses whereby the finer and more clayey material was laid down with the calcareous sand. The continental uplift which brought northeastern Vermont above the sea level and caused the deposition of sediments to cease occurred at the end of the Ordovician.

E.

BRADFORD SCHIST.

This name was used by the writer in 1898 to designate the non-calcareous member of the calciferous of mica schist Prof. Hitch-

PLATE XXX.



Horizontal position of Limestone, West Danville, Vt.

cock. Bradford was chosen for several reasons. It is the most important town in Orange County bordering the Connecticut River. The rock exposures are easy of access to all geologists visiting the area. This is especially true in following up the Waits River Valley to Cassville. Here the schist reaches its typical development. The breadth of the exposure is about seven miles; the schists are highly folded and contorted. To the south it grades into a micaceous quartzite with perfect parallelism of the scales of mica between the layers of silica. In many instances it becomes gneissoid in appearance, to the north it is finer grained often phyllitic and ottrelitic. The fine grained nature of the northern portion is nowhere better illustrated than in St. Johnsbury ,east of the Passumpsic River and west of East St. Johnsbury.

The name Bradford schist includes all the non-calcareous members of the old "Calciferous mica schist." It embraces therefore the quartzite, staurolitic, actinolitic, amphibolitic, ottrelitic, graphitic, and garnetiferous phases lying between two large narrow belts of slate and shale, one on the east near the Connecticut River, the other on the west passing through Newport and Montpelier to Barnard.

The average strike of the belt is practically parallel with that of the Washington limestone N 10° E in the southern portion, N 20° E in the central, N 40° E in the northern. The dip is at a very high angle, either east or west and the whole series of schists suggest complex and intricate folding into anticlinal arches and synclinal troughs. On the brow of the hill to the west of East St. Johnsbury many of these anticlines can be seen and some have been photographed. Like Appalachian foldings the western slope of the anticlines are everywhere the steeper of the two. These sharp folds are suggested in the diagramatic structural section accompanying this report. The planes of superinduced cleavage are not always coincident with the planes of deposition. Sometimes the variation will be marked by only a few degrees as on the southeast side of Kirby Mountain, while occasionally they are nearly at right angles with each other.

The Bradford schist alone was supposed to represent about one half the thickness of the "Calciferous mica schist" which Dr. Hitchcock has represented as 12,000 feet. The depth of 6,000 feet appears by the complex folding to be too large an estimate. It often makes its appearance overlying the Waits River limestone in bands only a few hundred feet in thickness and small narrow bands in unmapable area are interstratified with the arenaceous limestone.

Some of the different phases of the schist demand special consideration. In the northern portion on the east it graduates by almost insensible gradations through shaly material into the Waterford slate, so that no sharp line of demarcation would suggest an unconformity between the two. On Observatory Knob, one half mile west of St. Johnsbury, there seems to be a very peculiar relation between the Waits River limestone and the Bradford schist. The former in a quite unexpected manner grows poorer and poorer in its lime contents until the uppermost portions become entirely free from lime, and the phyllites predominate. This transition by imperceptible gradation from a siliceous limestone well suited for structural purposes to a phyllite schist with sufficient rift and grain for flagging stone have been observed in the same quarry face, I think only by Dr. W. J. Miller, of Hamilton College, in the Piedmont region of Maryland. The fact that the stone and phyllites dip 35°-45° E is suggestive that the two were laid down in conformity with each other, and that the subsequent superinduced cleavage is at an angle not far removed from 45 degrees with the planes of bedding.

If the crest of the hill alone be examined one would catalog the area from topography as Bradford schist; from the lower altitudes he would plot the area as Waits River limestone. But every quarry however small that has been opened upon the higher altitudes shows this gradational feature with descent from the lime impoverished schist into the typical limestone of the area involved. Whether the continued working of the Guyer quarry for building purposes will throw additional light upon the problem is an open question. The problem most certainly is suggestive.

One mile to the east the nature of the schist has entirely changed. It has become graphitized and the dips are at high angles. There is a suggestion of a possible fault along the incisional valley of the Passumpsic between the Waits River limestone and the Bradford schist which is here shown to be the younger member.

Another phase of the Bradford schist is well represented in a dumb bell shaped area of considerable dimension in Marshfield, Cabot, Walden, Stannard, Wheelock. It is five miles wide both to the north and south while in Walden it nearly disappears. The belt is highly staurolitic. Nearly all exposures are thickly studded with magnificent cruciform twins so beautifully penetrating each other that the impassioned collector is discontented with a mere specimen of regulation size. This is especially true in Cabot on the crest of the hills to the west of St. Joseph's Lake where the staurolitic schist lies in a gentle synclinal fold with the low dip of five degrees to the west, and in the road bed passing over Wheelock Mountain from Stannard to South Wheelock.

It is to this member so stoutly resisting both disintegration and erosion that the remarkably higher altitudes of Wheelock and Stannard are due. Wheelock Mountain maintains an altitude of sufficient proportion for a signal to be seen off the Atlantic Coast, although the mountain is 150 miles inland and nearly fifty miles west of the White Mountains. Such a signal was there planted in the eighties under the direction of Prof. Charles H. Pattee.

Another unusual and remarkably interesting phase of the Bradford schist is found in Barton about two miles east of the village near the road to Westmore. The exposure here somewhat suggests a gneiss but it very closely resembles a minette, the difference being not in the large black scales of biotite but in the ground mass. The hand specimen may be catalogued a biotite schist with perfect parallelism of the black scaly mica. A microscopical section is necessary in order to determine how feldspathic the material is. The section is not noted for its size but for its striking peculiarity. It is cut through by large masses of exceedingly dark biotite granite. The introduction of this intrusive has had much to do with the high degree of metamorphism of this peculiar member; in fact the preponderance of biotite in the granite suggests that this biotite schist has suffered sufficient fusion to cause its transition into a black biotite granite.

An arenaceous phase of the Bradford schist is found in Marshfield. In fact it is strikingly suggestive of a micaceous quartzite, in which the mica in small scales has carefully arranged itself with perfect parallelism, and the fine grains of quartz were originally granules of fine gray sand. About two miles east of Marshfield village this arenaceous variety has been largely used for whetstones. They are free from small garnets; they possess a clear grit and do not gum. Several other localities exist in northeastern Vermont where this local use of the arenaceous phase is apparent.

Other phases of the Bradford schist might be described, but cannot be discussed in the present report.

These various phases of the Bradford schist not only suggest different degrees of metamorphism but different conditions of the sea at the time of their original deposition. The whole suggests a rising continent toward the close of Lower Trenton time. The coarser material seems to have been laid down in reasonably close proximity to an old shore line. The drainage of contiguous areas was fairly rapid so that coarse sediments were transported into the Ordovician sea and with checked velocity deposited the sediments. The finer sediments were carried out into deeper water and therefore laid down further away from the shore. The sea was the more shallow toward the south and deepened quite rapidly toward the north, for the southern portion carries the coarser material and the northern portions the finer. A striking difference in the character of these oceanic sediments can be observed by comparing the Bradford schist in Cassville four miles from Bradford up the Waits River Valley with that at East St. Johnsbury along the Moose River Valley.

The continental rise may have been temporarily arrested and in fact slight subsidence introduced to allow for the deposition of the finely triturated clays whose metamorphic representatives now appear in the two belts of clay slate flanking on the east the Bradford schist and on the west the Washington limestone.

F.

MONTPELIER SLATE.

The following terms, Montpelier slate, Northfield slate, and Montpelier and Northfield slate, have been used interchangeably and indiscriminately in the various reports on the geology of Vermont. If there has been any discrimination whatever, "Northfield slate" has been used more in a commercial sense than in the designation of a geological formation.

I would propose therefore the single term Montpelier slate for the terrane that has been formerly discussed under these different names. The name Montpelier is chosen for several reasons. It is the capital of the State and no other geological formation has received the adjective Montpelier in its description. It is in Montpelier that the slate is the most easy of access for all who wish to study its characteristics. Here it has reached its greatest breadth and highest development. Here it is, scarcely outside the city limits, if at all, on the farm of Charles T. Sabin that it has been extensively quarried for roofing purposes.

The name Montpelier then is here applied for the first time in a purely geological sense to the belt of slate that flanks the pre-Cambrian schist to the east of the Green Mountain axis, lying conformably upon and often interstratified with the Waits River limestone. Its southern terminus is in Barnard, Vermont, from thence it extends intermittently through Northfield and Montpelier, Irasburg and Newport into Canada on the north.

The entire series is a highly metamorphic rock derived from beds of plastic clay. Its perfect cleavage is the direct result of molecular rearrangement through heat and pressure, whereby the mineral grains are flattened and rotated into planes parallel to each other. These planes may or may not coincide with the planes of original deposition of the clays. In Northfield there is a striking difference between the two, the cleavage being at a high angle while the planes of bedding are at a low angle to the west. In the northern areas the two planes seem to coincide. This is especially true in Canada, where in a contiguous area the diagnostic fossil graptolites are most beautifully preserved.

The black color of the Montpelier slate is due to fine carbonaceous particles disseminated through it. The color and texture is quite uniform, although in the more southern portions of this narrow belt the slate assumes a bluish black hue and a finer texture, while in the north it becomes a jet black and sometimes approaches a carbonaceous shale. This latter feature is very distinct on the west of the Black River in Albany.

This slate differs somewhat from the Waterford slate which is discussed in the next section of this report. It is darker and more uniform in color, less laminated in structure, and freer from all secondary minerals. Therefore it is better suited for roofing purposes, blackboards, sinks, stationary washtubs, etc.

The general trend of the strike is at first north and south, then it changes in Northfield to N 30 ° E and from thence maintains the same general direction to Lake Memphremagog. The slate in the southern portion stands in nearly a vertical position. In Albany it dips 65 ° W, in Newport 80 ° W.

Although this belt of slate has been often mapped as passing through Wolcott, I am confident that it was a generalization, for a detailed section running from Hardwick to Wolcott, the last six miles of which was over pre-Cambrian terranes, revealed no slate whatever, only 660 feet separates the last outcrop of the limestone from the first of the pre-Cambrian schists. The slate is not embodied in the structural section because in the neighborhood of Hardwick it seems to have been either squeezed out entirely or have suffered sufficient denudation for its complete removal. From Albany the slate can be traced with considerable definiteness, in spite of the morainic material mantling the area, to Lake Memphremagog; and from thence across the lake into Canada, where its fossiliferous nature is well shown.

The contiguous land areas were approaching base level and therefore yielded their constituents to sedimentation the more slowly. The waters receiving the sediments were comparatively quiet, thus allowing the deposition of the finest clays and muds. The grand continental uplift that brought the northeastern section above sea level occurred at the close of the Ordivician, and the oceanic connection with the Gulf of St. Lawrence was closed.

G.

WATERFORD SLATE.

The introduction of the term Waterford slate, as it is new in geological literature, demands an explanation. It is here used to locate a narrow belt of slate that may or may not be the equivalent of the Montpelier slate already described.

This terrane flanks the Bradford schist on the east, and is separated from the pre-Cambrian metamorphic series by a fault. Lithologically it is a slate graduating into a fine grained phyllite of the Bradford series to the west. In Waterford it reaches its maximum thickness, 400 feet of workable slate. It extends northward through Concord, Kirby, and Burke, where it seems to terminate although detailed field work in the unexplored granitic area to the north may reveal outcropings of the slate still nearer the International Boundary.

Its strike in Waterford is N 10° E, dip 80° to 85° E, with apparent planes of bedding nearly coincident with those of cleavage. The slate appears in many towns bordering the Connecticut River as far south as Guildford. Presumably it is all Waterford slate. Occasionally as in Bradford the slate has been squeezed out entirely or has been removed by erosion so that the slate is not a continuous belt from Burke Mountain in the north to Guildford in the south. The strike varies from N 45° E in Norwich to N 10° E in Waterford and the dip from 60° W in Hartford to 80° E in Waterford.

In general the slate is a dark gray compact tough laminated rock often studded with incipient staurolites, occasionally with iron pyrites. In Thetford it becomes soft and extremely fissile, and assumes a bluish black hue. Several localities from time to time have yielded small quantities of the slate for economic purposes, cemetery work, flagging, underpinning, roofing, and road material.

The Waterford Slate Company in 1855 spent several thousand dollars in developing the quarry on Waterford Mountain two miles south of East St. Johnsbury on the St. Johnsbury and

Lake Champlain Railroad. In 1860 it is reported to have been sold to Webster and Keys of Concord, New Hampshire, for $7,777. They became involved in litigation and a foreclosure ensued. There seems to be no reason why the quarry should not be worked at good profit with modern machinery and modern methods. I have split with a single blow of a trimming hammer samples three feet long and from two feet thick to the thickness of one quarter of an inch. The grout around the old quarry exposed for half a century shows how stoutly the slate will resist disintegration. A seventy five foot front can be easily obtained with excellent opportunity for grout beds.

A peculiar wall-like rock suggestive of a basaltic dike about ten feet in thickness stands directly in front of the face of the quarry. It is a compact, highly metamorphic mica schist consisting essentially of quartz and brown mica. Its peculiar feature is the pebbles of quartz and the small crystals of some secondary mineral that demands microscopical investigation. It suggests in some ways a basal conglomerate. If it is such, then an erosional unconformity exists between the slate and the highly metamorphic series to the east. Bosses of granite appear in the slate both on Waterford Mountain and in Kirby. The Waterford slate has also been quarried in Fairlee, Thetford, and Guildford, but not to large extent even though the quarries are near the Passumpsic Railroad.

The condition of the adjoining land areas yielding the sediments and the character of the waters in which they were laid down were not materially different from those involved in the discussion of the Montpelier slate therefore they need not be introduced anew.

H.

IRRUPTIVES.

a. Granites.

The term granite in this discussion is used in a geological rather than a commercial sense. It excludes the gneisses in which a certain parallelism of some accessory constituent has been developed in the rock mass, usually of sufficient importance to be recognized even in the hand specimen. It includes the heterogeneous series of holocrystalline irruptives whose essential constituents are quartz and some acid feldspar, generally orthoclase, and some accessory mineral either mica, or hornblende, or both.

Scarcely a town exists amongst the fifty two towns under consideration that has not suffered the introduction of these acid intrusives. That these granites are not the residual backbone of mountains formed from sedimentary deposits by complex folding is perfectly plain, for they have developed many new minerals through contact metamorphism. One of the best illustrations of this phenomenon is the large crystals of calcite along the zone of contact between the granite and the Washington limestone through which it was irrupted. Their surface exposures are often tarnished with the oxides of iron resulting from the decomposition through oxidation of pyrites. Even in many such localities as soon as the sap rock has been removed excellent building material, permanent in color, is obtained.

There is a considerable difference in the texture of the granites in northeastern Vermont, even among those belonging to the same irruptive period. In general the more southern areas are the finer grained though there are some striking exceptions to this rule.

The Knox Mountain granite in Orange is much coarser than the Kirby granite on Kirby Mountain, while the Barre granite is distinctly finer than the high grade granite of Graniteville, Province of Quebec, just north of the International Boundary.

A few of the areas that have produced large commercial outputs or are fully capable of doing so with the expenditure of a limited amount of capital to open up the industry are worthy of careful consideration. The Barre granite that has been so ably discussed by G. I. Finlay in the third report of the State geologist on the "Mineral industries and geology of certain areas" needs no further comment, save by way of comparison of analysis.

The next field of importance although lying in the extreme northern part of Washington County is found on Woodbury

Mountain. While this area has been discussed somewhat in the past, new facts have been brought to light that have never been published. The author first visited this area with Prof. Hitchcock in 1895 when I measured blocks one hundred feet long and seven feet deep without seam or flaw. It is doubtful if a larger shaft can be obtained at any quarry in the world than upon this mountain.

The Woodbury Granite Company is one of the largest and best in equipment of any kindred company in the United States if not in the world. Through the kindness of Mr. George H. Bickford, its manager and the president of the Hardwick and Woodbury Railroad, I have had many excellent opportunities of carefully examining both the quarries on Woodbury Mountain and the processes used in the manufacture of the stone. The granite is situated six miles south of the village of Hardwick and is reached by a railroad owned and operated by the Woodbury Granite Company.

The quarries are situated upon the brow of the mountain where a 300 foot working face is easily obtained. The adjacent valleys furnish an excellent site for the disposal of the grout for the mountain is a residue of erosion and nearly surrounded with deep incisional valleys in the Waits River limestone. The quarry is entirely open cut work and the stone is not surpassed by any in durability, permanency of color, beauty when polished, ease of working, and seldom in resistance to compression. Its remarkable freedom from all accessory injurious constitutents renders it a special favorite for such constructions as the pedestal of the Sherman monument in Washington, the new Pennsylvania State House at Harrisburg, and the Rock Island Railroad Station at Chicago.

Inasmuch as the granite on the crest of the mountain owned and operated by the E. R. Fletcher Company possesses the same general characteristics and in fact is the same main stock it seems advisable before taking up the analysis to note the work of the company. Whatever the Woodbury Granite Company quarries can yield, the Fletcher quarries can duplicate save the height of the working face and the ease of working the stone.

No town in Vermont or the United States is more dependent upon its granite industry than Hardwick. Without it, the thriving village would cease to exist as such and only a few dwellings would mark the site of the present prosperous town. Twelve hundred men are employed in the industry. The monthly payroll of the two Companies exceeds $50,000 and the annual output of granite $1,250,000. Four-fifths of this comes from the Woodbury granite alone.

While the town of Bethel in Windsor County lies entirely outside the area of this report, I beg leave to call attention to the only known granite of its kind. Not on account of its striking peculiarities, but because its chemical analysis is available for comparison and because it is in part owned and operated by the Woodbury Granite Company and worked both at Bethel and Hardwick. The Ellis Company, of Northfield, also operates the same general stock, cutting the stone at their large sheds in Northfield, rather than in Bethel.

The striking peculiarity of the Bethel granite is the utter absence of a pigment in its essential constituents, the paucity of accessory minerals, and its unexpected compression strength. With only a few dark blotches occasioned by scales of mica it assumes a whiter appearance than any known granite, in fact whiter than nearly all marbles, even the yellow waxy luster of the Italian prototype of our own Vermont statuary marble. It can be cut and carved with readiness into any form to serve human desire. When polished these dark blotches become more prominent but they are scarcely noticeable upon the hammered surface. I have compared a five inch cube of this granite with hammered faces, with the interior of buildings painted with lead carbonate and with zinc oxide and found the Bethel granite to be the whitest of the three. For the construction of massive buildings of permanent white color the stone is without a peer.

Through the interest of Mr. G. H. Bickford I am able to present here a copy of the chemical analysis and compression tests made at the Watertown Arsenal, Massachusetts.

Chemical analysis of the Woodbury gray granite, quarried by the Woodbury Granite Company, Woodbury, Vermont.

Silica	SiO_2	70.75
Oxides of iron	Fe_2O_3 FeO	2.70
Aluminum	Al_2O_3	15.80
Lime	CaO	2.03
Magnesia	MgO	1.35
Soda	Na_2O	3.88
Potash	K_2O	3.46
Loss at red heat	H_2O	.35
		100.32

Correct,
(Signed) E. K. MacNutt.
(Signed) F. E. Hobbs,
Major, Ord. Dept., U. S. A.,
Commanding.

Chemical analysis of Hardwick white granite, quarried by the Woodbury Granite Company at Bethel, Vermont.

Silica	SiO_2	72.70
Oxides of iron	Fe_2O_3 FeO	Trace
Alumina	Al_2O_3	18.35
Lime	CaO	2.80
Soda	Na_2O	4.52
Potash	K_2O	.95
Loss at red heat	H_2O	.60
		99.92

Correct,
(Signed) E. K. MacNutt,
(Signed) F. E. Hobbs,
Major, Ord. Dept., U. S. A.
Commanding.

In introducing for comparison an analysis of the dark granite from Millstone Hill in Barre, made by G. I. Finlay, given on pages 55 and 56 of the State Report, 1901-02, I find a strikingly close resemblance in the three granites.

	Barre.	Bethel.	Woodbury.
SiO_2	69.89	72.70	70.75
Al_2O_3	15.08	18.35	15.80
Fe_2O_3 FeO	2.50	Trace	2.70
MgO	.66	——	1.35
CaO	2.07	2.80	2.03
Na_2O	4.73	4.52	3.88
K_2O	4.29	.95	3.46
H_2O at 110 and ignition	.54	.60	.35
P_2O_5	——	——	Trace
	99.76	99.92	100.32

By comparison of these analyses it will be seen that the Bethel granite is the most acid, the Barre the most basic, the Woodbury granite intermediate between the two; that the soda-feldspar, albite, predominates in the Bethel stock almost to the exclusion of the potash feldspar, not only found so abundantly in the Barre and Woodbury granite but the common feldspar of our New England granites, and that the oxides of iron are practically absent from the Bethel stock while present in the others. This can be explained by the paucity of the scales of mica which being complex silicate of aluminum, magnesium and iron would yield the oxides of iron in their chemical analysis. Another interesting comparison can be made in the compression tests of the Bethel and Woodbury granites. These tests, like the chemical analyses, were also made at Watertown Arsenal, Massachusetts, by which the vastly superior strength of the Bethel stone will at once become apparent.

Test No. 13,261.

Woodbury Gray Granite, quarried by the Woodbury Granite Company, at Woodbury, Vermont.

First crack.	Ultimate strength.	
	Total.	Per o inches
Pounds.	Pounds.	Pounds.
199,000	203,500	22,460
181,000	181,000	19,850
168,000	184,000	20,110
Pyramidal fractures, Average,		20,806.

Correct,
J. E. Howard.

F. E. Hobbs,
Major, Ord. Dept., U. S. A.,
Commanding.

Test No. 13,261.

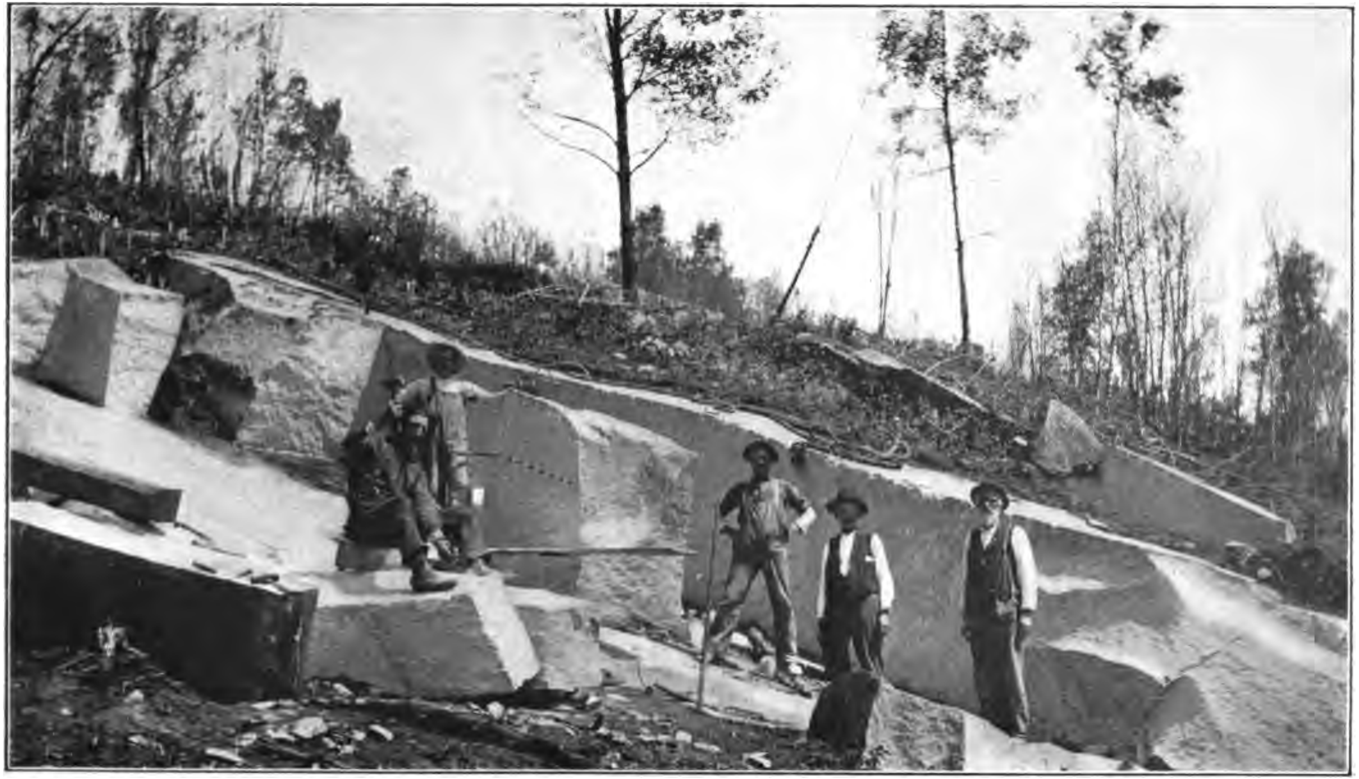
Hardwick white granite, quarried by Woodbury Granite Company, at Bethel, Vermont.

First crack.	Ultimate strength	
	Total.	Per o inches
Pounds.	Pounds.	Pounds.
287,000	307,000	33,120
301,000	318,400	34,350
272,000	388,900	31,990
Pyramidal fractures, Average,		33,153

Correct,
J. E. Howard,

F. E. Hobbs,
Major, Ord. Dept., U. S. A.,
Commanding.

PLATE XXXI.



Granite Quarry on Kirby Mountain.

A few compression tests of well known granites will show the strength of the Vermont stone and its suitability for structural purposes:

	Strength per Square Inch.
Hornblende granite, Bay of Fundy	11.916
Biotite granite, New London, Connecticut	13.338
Biotite granite, Westerly, Rhode Island	16.077
Biotite granite, Vinal Haven, Maine	16.770
Hornblende granite, Quincy, Massachusetts	16.750
Biotite granite, Barre, Vermont	19.560
Biotite granite, Woodbury, Vermont	20.806
Biotite granite, Milford, Massachusetts	22.610
Hornblende granite, St. Cloud, Minnesota	28.800
White granite, Bethel, Vermont	33.153

The Bethel granite shows a strength in resistance to compression more than twice that of the beautiful Westerly, Rhode Island, stone and vastly superior to that of any other known granite. Special attention should also be called to the fine light granite of the Northern Granite Company of Hardwick. The granite is in Hardwick rather than in Woodbury and from it more than fifty fine statuettes have been cut. The same company operates the quarries at Mackville one mile east of Hardwick village. A considerable quantity of granite is also found on Buffalo Mountain to the west of Hardwick. This latter intrusive is not in the Washington limestone but in the pre-Cambrian terranes.

The next field of importance is in Kirby about five miles north of West Concord, not so much from the annual output and the number of men employed as from the striking resemblance of the stone to Barre granite and its universal application. Several quarries have been opened within the past two years. One of these is shown in Plate XXXI, where the length and thickness of the upper beds can be readily seen. This photograph was taken at the new quarry of the Burke Granite Company. The photograph does not do justice in any way to the quarry. Last summer the author found a large area uncovered and sheets many times thicker and larger than can be hauled down the mountain side ready for quarrying.

The work is under the management of Joseph Welch who will open another large quarry this summer to the north of the one represented in Plate XXXI. A part of this stone is cut at West Concord, part at St. Johnsbury; and a part shipped to local cutters elsewhere.

A word might be offered in respect to the properties of Mr. Kearney as they are not included in what is commercially known as Burke Mountain Granite. In June, 1905, Mr. Kearney had several quarry sites opened up ready for sale of stock or quarrying. The granite lies on either side of the road leading to the quarries of the Burke Granite Company on Kirby Mountain. A small brook runs between the places now uncovered as quarry sites. There exists also an easy disposal of grout. The granite is of good grain, even texture, comparatively free from iron and black knots. Like other granite around Kirby Mountain it is susceptible of a fine polish. It affords an excellent opportunity for investment, for the stone is unlimited in supply, and situated only four miles from West Concord, where it finds a ready market, selling in the rough at sixty cents per cubic foot.

The granite of Blue Mountain is a dark biotite granite susceptible of a fine polish and extensively used. The pay-roll for cutters alone is $350 per diem.

In Groton a large mass of fine grained biotite granite has been irrupted in the Washington limestone. The stone seems to be growing in favor each year for both monumental and structural purposes. The largest quarry is situated just south of the village of Groton from which more than 2,000,000 cubic feet of stone have already been taken.

About thirty years ago a granite site was discovered and a quarry opened in Derby, Vermont. For a quarter of a century it met only a local demand. The permanency of the stone was reassured by recent inspection of shafts and monuments so long ago removed from the quarry. About four years ago the Newport Granite Company was formed with offices in Newport, Vermont, and Albany, New York, under the presidency of A. A. Flint,

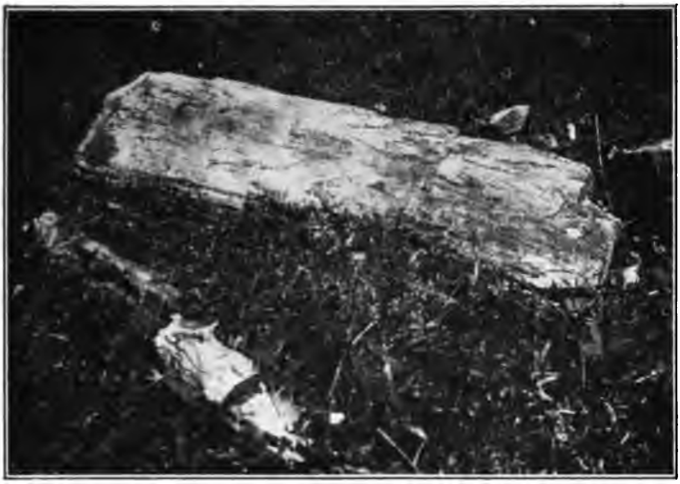


Fig 1.
Feldspar Crystal, Cabot, Vt.

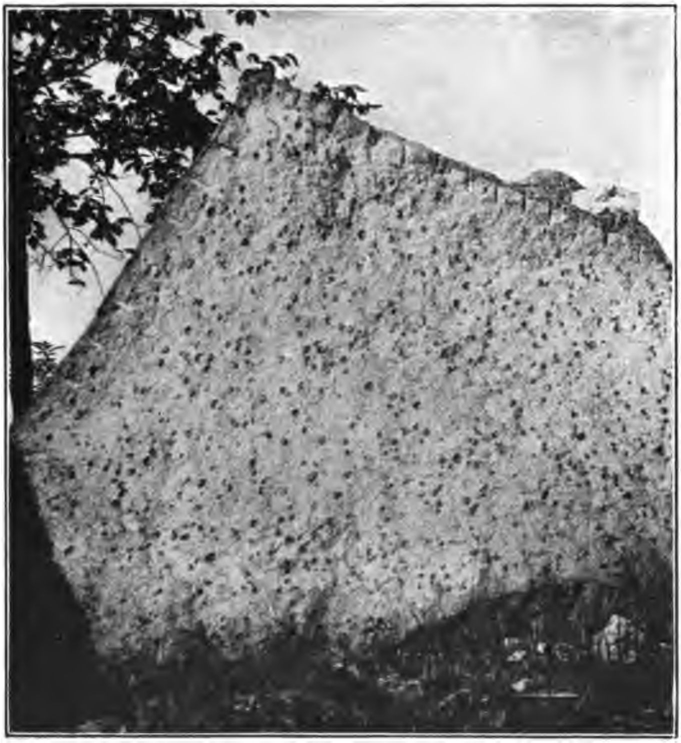


Fig 2.
Craftsbury Granite.

and the quarry management of George Farquharson. The supply of this stone like that in so many other localities is inexhaustible and like the other high grade granites it lies in the Washington limestone. For permanency and evenness of color the stone is not surpassed by any quarry in New England. As the output has been estimated by Mr. Farquharson as $90,000 for 1906, we may expect even a much larger and more profitable industry in the future.

At West Danville there lies the possibility of another large granite industry. St. Joseph's Lake as already noted elsewhere is four miles long and one mile wide. At its outlet where the granite sheds are situated, the available water power can scarcely be surpassed. Many excellent quarries can be opened up within five miles of the lake. The best of these is in Peacham about four miles southwest from West Danville.

In Cabot just at the head of St. Joseph's Lake there is a very peculiar pinkish white and tough granite on the farm of Asa B. Mack. It is noted for its close resemblance in certain localities to the famous cassiterite bearing greissen of Cornwall, England, and in hand samples to lepidolite.

The feldspar has been largely replaced by quartz, and biotite is entirely absent. The scales of mica are white or pink and exceedingly small. The feldspar when present may be albite. In fact it is so fine in many sections that a microscopic slide would be necessary to determine its nature.

Associated with this fine grained variety are some exceedingly coarse phases. It carries crystals of feldspar that have assumed large proportions. A single crystal of albite, the sodium feldspar, exceeds four feet in length and two feet in thickness. Plate XXXII, Fig. I, represents a fragment of such a crystal lying by the roadside. In this albite there are intergrowths of orthoclase, the potassium feldspar. The cleavage of this mineral is so highly perfect that many fine hones have been fashioned from it.

On Miles Mountain to the north of Miles Pond can be found hundreds of acres of good quarry land. Two distinct varieties of granite can be obtained, one light, the other exceedingly dark, in fact it may be designated black granite. In the former variety the mica is biotite and the orthoclase a pure opaque white. This property is largely owned by W. L. Hastings of Miles Pond. I. H. Brown has several acres of granite lying within one mile of the railroad in sheets with perfect ritt and cleavage. The stone ought to be worked with good profit. The black variety is one of the handsomest granites ever seen in Vermont.

It has often been said that no red granites exist in Vermont. Perhaps they do not in considerable quantity. The largest exposure known in the State is in Newark about fifteen miles from West Burke, ten miles from Island Pond, and on land owned by Charles E. Silsby of West Burke. A long ledge of granite is here exposed to view, sometimes rising 185 feet with vertical face, and a 400 foot working face could be easily obtained. It is in this ledge that in 1905 I found Vermont's red granite. The rock is strikingly suggestive of famous Scotch granite of Peterhead, and may well be used in place of it. The feldspar in part is red and in part white. It is susceptible of a fine polish and so far as can now be ascertained permanent in color.

The red variety has been reported from the west side of the mountain also. Its distance from any railroad is the one great difficulty in way of the rapid development of a good industry in Newark.

Another granite demanding more than a passing notice is found in Craftsbury just east of the village. It has found its way into more museums than any other granite of the State. It is noted not for its economic uses but for its peculiar orbicular structure. Large concretions of biotites are thickly scattered through the rock mass; so suggestive are they of fossil fruits that they have been catalogued "petrified butternuts." Plate XXXII, Figure 2, represents the black face of such an orbicular granite. This peculiar granite has been reported in much smaller areas as far north as Stanstead, Province of Quebec, and as far south as Northfield. Erratics have been transported many miles by the ice in a southeasterly direction even over Wheelock to South Wheelock already noted elsewhere. The granite has been thoroughly discussed by Dr. E. Hitchcock on pp. 563-565, Vol. II, Geology of Vermont, 1861. Kindred varieties have been found in Rhode Island, North Carolina, Finland, Sweden and Sardinia.

Space forbids the mention of scores of other localities where granite is found in northeastern Vermont, and in several instances where it is worked at the present time as in Irasburg, Salem and Norton, but the detailed mapping of the area I trust will bring all of these to the attention of the general public.

b. Gneiss.

Gneiss differs from granite only in the parallelism of its accessory mineral which may be either mica, or hornblende, or both. The commercial world scarcely recognizes the distinction. Parallelism may not be detected in hand samples but be apparent in the quarry face so that the curator of a museum would catalogue his sample granite, while the geologist in the field would label it gneiss. In fact by insensible gradation the one passes into the other.

Like granites gneiss may be developed either from the metamorphism of sedimentary rocks through heat and pressure or from igneous masses. The origin of the gneiss in northeastern Vermont is doubtless the latter. One area flanks the Connecticut River in Maidstone and Guildhall and appears also in Waterford. Before it can be accurately discussed it needs further study. It may be the same as the large area of gneiss around Bellows Falls.

A second locality entirely different in color and character of the quartz is found in Concord, one mile north of North Concord. It is a highly metamorphosed and contorted rock, dark gray in color, with its scales of biotite arranged in perfectly parallel layers. How far this belt of gneiss can be traced to the north is unknown.

c. Dikes.

The intrusives of northeastern Vermont are numerous and sometimes cover large areas. They range from the strongly acid pegmatites to the strongly basic diabase. When the term pegmatite is considered in its older sense, namely that of a graphic granite, it finds a most excellent representative in Westmore at the foot of the perpendicular cliffs of Mt. Hor. Here the true graphic character is well established. The quartz is quite abundant, and closely resembles the arrowhead characters of Assyrian inscriptions, while the crystals of feldspar are large and perthitic. It may have been intruded in connection with the closing phases of igneous activity. Time forbade the study of its relation to intrusives of the earlier stages.

When the term pegmatite is considered in the light of the later years as applied to coarse veins of granite with large crystals of feldspars and micas predominating, many occurrences are found in nearly every town. They traverse the preceding formations in all directions. Their detailed study presents a very interesting problem.

Diorites.—These granitoid rocks are more numerous in the older pre-Cambrian series than in the Ordovician. They range from the normal diorites, consisting essentially of plagioclase and hornblende, to the quartz-mica diorites. The former variety is far in excess of the latter and is well distributed throughout the eastern area. The latter finds a peculiar and intensely interesting rock mass that needs further study in the vicinity of Miles Pond. The mica is brown biotite and the hornblende is both brown and green. The ground mass is highly altered and the rock weathers with a peculiar pitted surface.

Gabbros.—Gabbros are very numerous within the area. Some of these are fine grained granitoid rocks as in Barnet while others are extremely coarse as in the second railroad cut below East Barnet where it is sixty-six feet wide and extends several miles in a northeasterly direction strikingly suggestive of a batholith.

Diorite Porphyra.—A considerable area of this igneous rock is found in Essex County cutting the highly metamorphic pre-Cambrian schists. The green color and bladed structure of the hornblende suggests a secondary origin, while the phenocrysts of feldspar are greatly decomposed.

Diabase.—Dikes of diabase are common both in the highly

PLATE XXXIII.

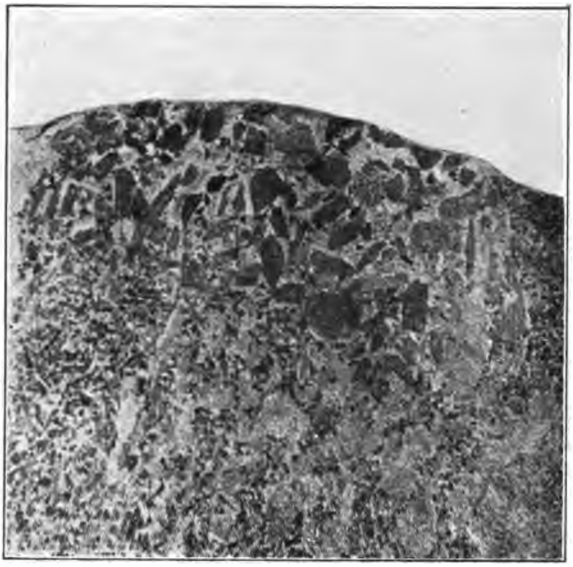


Fig 1.
Brecciated eruptives cemented together by granite, Concord, Vt.

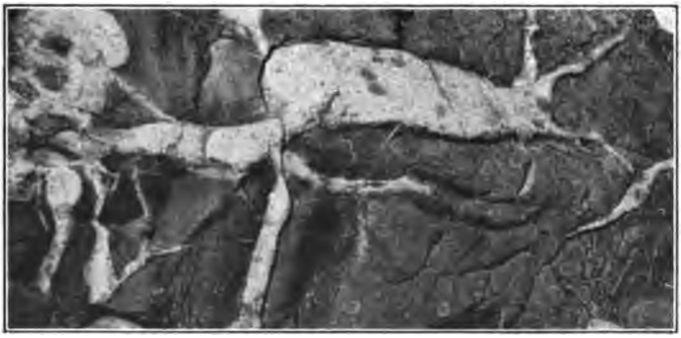


Fig 2.
Veins of granite in a porphyritic diorite, Lunenburg, Vt.

metamorphic and the limestone series. By their peculiar composition some of these suggest cord wood, others what is known as the onion structure, where they cut the limestone in a vertical position. Sometimes they run east and west, sometimes northwest and southeast but always at some angle with the strike.

Sometimes they are amygdaloidal and of the camptonite order, with large phenocrysts of hornblende. In Newark the augites are completely altered to chlorite and the feldspars much kaolinized.

Perhaps the most interesting of them all is the very handsome dike of amygdaloidal diabase in Westmore which cuts the Washington limestone and is completely studded with crystals of calcite.

Porphyrite.—Another basic igneous rock often appearing in the schists should at least be mentioned. It is so highly altered that little can be said without further study as to its original structure. The manganese and iron constituents are wholly altered and the typical feldspar unrecognizable. The white phenocrysts are set in a grayish and sometimes greenish background as at Boltonville.

To settle the age of these irruptives and their relation to each other will require further study. Some of the diorites and porphyries are younger than the granites. Plate XXXIII, Figure 2, shows a large number of granite veins penetrating a highly metamorphic diorite in Lunenburg. In Concord these more basic irruptives have been shattered in angular fragments and cemented together again by granite as seen in Plate XXXIII, Figure 1. Often large fragments of diorites and gabbros are found completely encased within the granite, therefore they must be younger. This, however, does not prove that there are no intrusives younger than the granite.

I.

CLAYS.

As I have already noted under the caption, Glaciation, the area considered in this report was subjected to an ice mantle in Pleistocene times. Beneath the ice and in its lowest portions various kinds of rock were ground to an impalpable powder which now consist of a hydrated silicate of aluminum bearing both mineral and organic impurities.

Scarcely a town exists in this northeastern section that is without its brick houses and its old brickyard. Inquiry has led in every instance to the definite statement that the bricks were manufactured from bowlder clay within the town. The comeliness of these dwellings testifies to the highly ornate character these home made brick now possess. While the most of these yards have been abandoned because timber was cheaper, yet a few remain and their products find a ready market. The largest of these is in East Ryegate owned and operated by Mr. M. H. Gibson. The brick are of a high grade and are shipped to the largest cities in New England.

Two small and less extensive plants are located at St. Johnsbury Center. These are operated by Alfred J. Rioux, who employs about a dozen men. The present capacity of the yards is 250,000 bricks worth from $6 to $7 per thousand, these are of permanent bright red color and have been shipped mostly to St. Johnsbury, Barton, Newport, Vermont, and Berlin, New Hampshire. The modified drift of the Connecticut, the Pasumpsic, and the Black River Valleys, furnish an abundance of high grade plastic clays well suited for structural purposes.

J.

PALAEONTOLOGY.

The discussion of this problem is so complete in the State Report for 1901-1902, pp. 94-99, that it seems inadvisable to take up the matter again in detail at this time. The author regrets that in the four years that have elapsed since the above report was issued no new light from the discovery of fossils can be thrown upon the problem. The Canadian area to the east of Lake Memphremagog, Lot XIX, Range II, has been visited with the observance of a goodly number of graphtolites in the black, clay slate that is lithologically identical with the Montpelier slate. If this belt of slate passes under Lake Memphremagog then it appears at Newport and should yield graphtolites. A diligent search around the lake will, I think, as soon as an opportunity presents itself, reveal these diagnostic features in Vermont.

A few more crinoidal stems have been found in Salem, on Salem Mountain, a few in Derby, and a few in St. Johnsbury, but their geological range is so great that they fail to throw new light on the problem. In samples the author has collected from Salem Mountain, Prof. C. H. Hitchcock thinks he sees some resemblance to fossil corals. In a fragment of the Irasburg conglomerate there is some evidence of a fragment of Favosites reticularis. It is a suggestion—I can say no more for it. In Westmore in the Waits River limestone there is also a suggestion of some species of Strophodonta. Although it may represent a cavity subsequently filled with pure calcite.

These evidences give no positive proof whatever and we are thus driven back to the contiguous Canadian areas for palæontological arguments and to lithological similarity of contiguous areas, to determine the true stratigraphical position of these heterogeneous terranes.

Accepting the Canadian diagnostic evidence as conclusive the uppermost members are Lower Trenton. This does not imply that the lower portions of the great body of Waits River limestone might not be older than Lower Trenton. Its formation may have begun early in the great Ordovician Sea, continued without unconformity, and ceased with the great continental uplift at the close of the Ordovician.

An attempt has been made to correlate this area with the Piedmont region in Maryland. The evidence is entirely in favor of a much younger series of rocks than those represented in the southern field. The distance of 550 miles from Baltimore is too great to allow lithological similarity much weight. While lithologically the Baltimore gneiss and the Setters quartzite with its stretched tourmalines may be duplicated, the Waits River limestone is devoid of the characteristic tremolites of the Cockeysville limestone. No evidence of fossils has yet been discovered in this southern field, while a few have been suggested in the northern area. No graptolitic slate or shale overlies either the Cockeysville limestone or the Wissahickon schist in the south, while in northeastern Vermont such a member seems to be present. If the Piedmont limestone is represented at all in this eastern section it may be in the lenses of limestone in Norwich and Lunenburg which most certainly are older than the Waits River limestone.

K.

PROBLEMS UNSOLVED.

The work that remains to be accomplished in northeastern Vermont is as follows:

(1). The careful field mapping of the entire area, which demands continued detailed field work. In this consideration Orleans County ranks first in importance, because of the possible diagnostic evidence in a fossil content in the less highly metamorphic section around Lake Memphremagog.

(2). The careful investigation of the extent and stratigraphical relation of the so called Devonian limestone flanking the pre-Cambrian schists to the west of the Waits River limestone.

(3). The extent and true significance of the Irasburg conglomerate, to settle the open question whether it forms the basal member of the Waits River limestone, or whether it is post-Waits River limestone and the basal conglomerate of the narrow belt of questioned Devonian.

(4). A most indefatigable search in the shales and slate around Lake Memphremagog for evidence of Lower Trenton graptolites that are so perfectly preserved in the shales at Castle Brook, Magog, Quebec. The brief time allowed for my reconnaissance has not permitted this much coveted investigation.

(5). The careful study of the numerous intrusive granites that have become a very potent factor in the commercial development of Vermont.

(6). The collection of all the irruptives in Essex County and the preparation of microscopical slides for petrographical study. This is necessary before many of these igneous rocks can be definitely named and their age determined. Many of these intrusives are so peculiar in character that they present a most important and intensely interesting problem.

(7). The study of the diorite porphyra, so well defined along the Moose River in Concord, to ascertain its relation to the metamorphic schists and sheared intrusives.

(8). The investigation of the fibrolite schist on Burke Mountain whose striking peculiarity is a large amount of fine sand disseminated through it in the form of magnetic iron.

(9). The extent of the gneissoid conglomerate in Granby and Victory and its relation to the Bradford schist.

(10). The nature and relation of the highly metamorphic Lunenburg schist catalogued in this report pre-Cambrian, as of old, with the confident prediction that it will ultimately fall in its true geological horizon Lower Paleozoic, probably Cambrian.

Note.—Since writing the above report the author has submitted to the Committee of Geologic Formation names at Washington, D. C., a list of names to be applied to the terranes of northeastern Vermont that might become permanent in Geological literature. Some of the names previously chosen and which appear in this report were found to be preoccupied. The final report of the committee was not received until it was too late to change the names in this present report. The sole object in the choice is to obtain uniformity with the work of the U. S. survey and thereby avoid duplication in formation names. The effect of this co-operation in preventing confusion must be decidedly beneficial.

The following names proposed by the writer have been unanimously adopted by this committee. Doubtless these names can be used in subsequent reports.

Lunenburg Schist as per report.
Waterford Slate as per report.
Irasburg Conglomerate as per report.
Waits River Limestone as per report.
Vershire Schist as a substitute for the Bradford Schist which name was pre-occupied; and Memphremagog Slate, for the Montpelier Slate which name was likewise pre-occupied.

C. H. RICHARDSON.

Photomount
Pamphlet
Binder
Gaylord Bros. Inc.
Makers
Syracuse, N. Y.
PAT. JAN 21, 1908

TN172 .R521
The areal and economic geology of N
Kummel Library APP5440
3 2044 032 914 152

Richardson, C. H. G72
AUTHOR
The areal and economic geology of
TITLE
northeastern Vermont.

DATE DUE	BORROWER'S NAME

DATE DUE

GAYLORD PRINTED IN U.S.A.